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AUTOMATED GENERATION OF SCENES BASED ON DLMS DATA BASE

DAAE07-86-C-R123

MAY 1989



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This technical report is prepared for the U.S. Army Tank Automotive Command under Contract# DAAE07-86-c-R123. The report details the work undertaken at George Mason University under sub-contract from Wayne State University. For effective utilization of the Vetronics Crew Display Demonstrator it is essential to be able to generate a number of realistic missions. This report presents a methodology to build an automated system to generate the missions.

The primary goal of this research project is to develop a methodology that will ebale the use of geographic databases for the construction of scenarios for the VCDD. In our analysis we have focussed on two Defence Mapping Agency databases - elevation database (DTED) and features database (DFAD).

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# Automated Generation of Scenes Based on the DLMS Database

Final Report
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## 1.0. Introduction

This draft technical report is prepared for the U.S. Army Tank Automotive Command under Contract # DAAE07-86-C-R123. The report details the work undertaken at George Mason University under sub-contract from Wayne State University. For effective utilization of the Vetronics Crew Display Demonstrator it is essential to be able to generate a number of realistic missions. This report presents a methodology to build an automated system to generate the missions.

## 2.0. Objectives

The primary goal of this research project is to develop a methodology that will enable the use of geographic databases for constructing scenarios for the VCDD. In our analysis we have focussed on two Defence Mapping Agency databases - elevation database (DTED) and features database (DFAD).

## 3.0. Background

The Vetronics Crew Display Demonstrator has been recently completed. Although some additional work is being done on the system, the current configuration is adequate to perform tests and simulations. It is recalled, that one of the major motivations of the VCDD was to provide a tool for testing alternative configurations for tanks and vehicles of the future. Given the current status of the VCDD development it is worthwhile to explore the means to be adopted to generate the test missions. The purpose of this report is to explore this issue.

In parallel with the VCDD development a major effort is underway in the Digital Mapping Agency and the Army's Engineering Topographic Laboratories to develop a detailed topographic database. The currently available databases are referred to as the Digital Land Mass System(DLMS) database. It is the particular goal of this report to detail a methodology which would help in rendering scenes based on these databases. We believe this approach would yield more realistic scenes rather than a purely polygonal approach. With the proposed approach the content, mix and configuration of the scene will be determined by the data available in the database.

The approach relies heavily on information contained in the DLMS database. This database is divided into two major components - the elevation database (DTED) and the features database (DFAD). Each of these is available at two levels of resolution usually called Level 1 and Level 2. The definition of the databases is available in [1]. On the basis of our discussions with the ETL personnel it appears that the DTED database is available for several areas while the DFAD coverage

is more restrictive. A brief summary of the DLMS database contents is available in Appendix II.

It is important to note that although the DLMS database is expected to be utilized for simulation and training [1], the database content has been strongly motivated by the need to have an accurate means of estimating radar cross-section sensitivity for different geographic locations. In other words only those elements which would show up as significant characteristics in a radar view are included in the database. It is clear that any use of the DLMS database cannot provide an exact reproduction of the scene. However, in this research we are trying to evaluate optimal strategy to construct scenes given the constraints of the availability of partial information.

There is active work underway to improve the quality of geographic and tactical databases. The Engineering Topographic Laboratories are a major sponsor of this work. They have designed a new database called the Terrain Tactical Database (TTD) which has higher level of resolution. This activity is at a fairly advanced stage of development. Currently an experimental activity is underway to verify the specification. For this purpose a cell of data located at Ft. Hood is being collected. This is one extension which needs to be carefully examined. Another future improvement is to build techniques of enhancing the VCDD scenes by supplementing with photographic information.

The information in these databases can be used to reconstruct scenes to build missions. The scenario is created by putting together graphical elements that correspond to the elements in the database. The effort required to create a scenario is based on the required accuracy, the required realism, the size of the data base and the number of missions generated. An important consideration in the effective use of the VCDD system is the ease with which vehicle-crew system performance can be evaluated in different environments, e. g., hilly, flat, mountainous, or sandy terrains, and rural or urban scenes. For this purpose it is expected that it will be necessary to generate a large number of missions.

Missions can be generated by manual placement of graphical elements. This step is a minimal requirement for generation of scenes. However, greater accuracy and realism needed for effective use of the simulator requires considerably more effort. Attempting this with manual methods would result in high cost and considerable elapsed time.

The framework within which this task is viewed is shown in Figure 3.1. The DLMS database is the input of our system and the object database is the output of the system. The object database is in turn utilized as the input to the VCDD system. This view

Figure 3.1 Integration of Image Reconstruction with VCCD.

is particularly significant because it shows how the approach derived from our research would be utilized to develop the input to the VCDD. Further, it is noted that while there are real-time constraints on developing the display from the object database, the processing constraints on the image generation task are less stringent. In the latter task much of the computation is expected to be undertaken in an off-line fashion. The computational complexity of the automatic scene generation task is very high and the ability to perform this task off-line improves the chances of success.

The Vetronics Crew Display Demonstrator is a simulator which must operate in real-time. This is obviously a constraint which must be satisfied at all times. To achieve this constraint it may be necessary to make compromises in image quality. The image reconstruction methodology must per force be constrained by this physical limitation. However, to reduce the negative impact of this constraint on image quality, we have formulated a requirement for the image reconstruction methodology.

This requirement is that the image reconstruction methodology must be flexible enough to provide capability for incremental improvement in quality. This property is particularly useful in situations in which the vehicle is moving slowly or the viewing angle changes slowly. In situations where the scene changes slowly, it is expected that we should be able to generate a higher fidelity and more realistic image. Our methodology is designed to fit within this environment.

At this stage we would like to emphasize that this approach is consistent with the studies in human perception. These studies show that if the scene changes rapidly then the human being does not focus in on the finer details, but as one dwells on the scene for a longer time we being to fill in the details.

Given the complexity of the computation task we have tried to build an hierarchical view on the distribution of the computation between stages. For example, it is expected that the object database will be formulated keeping this view in mind. To be specific, consider the impact of vehicle speed on the time available to generate the view presented to the user. Next impose on this the requirement of building higher levels of realism into the scene.

Obviously, this will lead to increasing demands on the computing resources. But on the other hand if the vehicle is moving at slower speeds then we would like to present the most realistic view. Our methodology suggests means to consolidate these two conflicting requirements within the same framework. In essence we suggest that the approach must be to build schemes which provide incremental improvement in realism, and we keep improving realism until the frame refresh time. In this approach

when there is little change in the scene (slow vehicle speed or slowly changing angle of view) the highest level of realism will be provided. In fact each successive refresh may actually increase the realism as perceived by the user.

The rest of this report is organized in four sections. In the next section we present the analytical basis for the scene generation approach suggested in the report. In Section 5 the overall methodology is discussed. The two most critical aspects of the approach deal with surface reconstruction and the use of fractals in approximating textural representations. These issues are discussed in Sections 6 and 7.

## 4.0. Analytical Basis

The construction of this system will require design compromises and tradeoffs between the constraints discussed in Section 3.0. In order for this system to function effectively, it is necessary to examine human factors and operator interfacing issues. The most important matters to be considered are the role of perception in the realism of reconstructed images, and optimal strategies for scene reconstruction. These are presented in the following subsections.

### 4.1. Perception Issues

Here we examine the need to identify those attributes that are important to the recognition of objects and what characteristics are necessary for the appearance of realism. Real time graphic presentation is a computation intensive process and it would be unwise to spend significant portions of CPU time attempting to display features that do not enhance the preceived realism of the object.

Likewise, it might be possible to identify some features that would be very easy to depict, and would considerably improve the realism of a scene. Including these features would be wise, even if they are not a part of the database and must be artificially introduced.

#### How "Real" is the Database

The data bases do not contain digital representations of the objects and landforms that actually exist at given place. Rather, they consists of, for example, a numeric code (identifying a category of objects) and coordinates indicating its location. Objects smaller than a certain size do not appear in the database: they are invisible to the sensor. This minimum visible size varies with the object; its texture and composition affect how big it must be in order that the sensor can detect it.

Although an object itself might be visible to some specific degree of resolution, the data base may not reflect that resolution. Features are assigned to a square (e.g., 200 x 200 meters) in a grid. There may be several features within the grid (each much smaller than the size of the grid), but there is no information describing where in the grid these features lie, nor how they are related with respect to each other.

Therefore, a scene constructed from the information in the database can reproduce the original view only down to some level of detail. A gabled house may exist somewhere within a square, but where within the square, its orientation, its color, its size, the number of windows, the position and type of nearby trees, etc., will not be found on the database.

This does not mean that a reconstructed scene is of no value. Nor does it mean that the quality of reproduced images would be poor. With suitable equipment, the reconstruction could approach photographic quality.

It does mean that the database can be used to generate realistic and representative scenes for purposes of training and testing. The scenes can be made realistic so they look like landscapes that actually might exist somewhere, but they would not be pictures of places that one could go and visit. The database contains a mix of varied features, and this could be used as a foundation for the generation of high quality reproductions of many scenes that would be indiscernible from an actual 'digitized' scene.

<u>The Role of Perception</u>
It is important to consider the question of how important a real, or at least realistic, scene is. Since these reconstructed scenes are to be used to evaluate instruments in their working environment, an individual's interactions during simulated usage would need to be monitored. Factors such as fatigue, error rates, reaction time, and other important performance measures, can be influenced by the selection and placement instruments.

The reconstructed scenes will also be used in the instrumented prototype for training. The same performance measures are important as assessments of both the effectiveness of the training environment and the level of learning attained.

Some of the factors that affect or do not affect the recognition and understanding of a picture or scene have been identified in the literature of psychological research. A perusal of these studies identifies items that need to be given careful attention in order for the reconstructed scene to appear 'natural'.

For instance, when viewing an image, the eye focuses on a

small portion of a picture (the area of primary importance and interest) while studying it. These areas tend to have high information content. Eye movements are short (less than 15 degrees) and fast. However, the parts of the picture outside of this region of interest are important during this period. Peripheral vision examines, and processes, these peripheral features as part of the mechanism that determines where next to direct attention [ANTE74].

Thus, even though a viewers attention is devoted to a small portion of a scene, the nature of surrounding features are being analyzed in an attempt to build a meaningful representation of the whole scene [YARB67]. This means that parts of the scene that are not the primary focus of attention must be present and must be coherent with respect to the overall organization of the picture.

When viewing time is short, scenes with more detail are superior where a high level of recognition or recall is important. In situations where scenes are changing very quickly, or where fast comprehension and reaction time is important, the quality of the scenes should approach that of a photograph [NELS74, LOFT75, LOFT79].

When the scene contains features the user does not expect or is unfamiliar with, an increased viewing time is required to comprehend the scene. Otherwise, one can expect an increase in errors of interpretation and judgement, and an increase in viewing fatigue.

Reproduction Quality

Studies have shown that the eye is drawn to areas of a picture that have high information content [PASN85, PASN86]. These areas have complex features (many short line segments, curved lines). Long straight lines have little information content, and as such, little attention is given to them. The quality of a reproduced scene can affect the information content of various local features. If the resolution of the display is insufficient, short line segments are lost, information is lost, and viewing and comprehension of the scene is affected.

Also, poor resolution introduces a jaggedness of lines that are at an angle with respect to the scan lines of the display [FOLE82]. This has the affect of simulating a feature with high information content, and will distract a viewer's attention from areas that would otherwise be examined. These points underline the need for high quality reproduction of the images.

## 4.2. Reconstruction Strategies

Images of natural scenes such as vegetation and terrain are characterized by the high degree of irregularity and detail that they possess. Most synthetic images, on the other hand, are visually very simple, often lacking significant small-scale detail, and are usually composed of highly regular geometric shapes such as polygons, lines and curves. This lack of realism has two major drawbacks when used in a simulator such as the VCDD: First of all, using such unrealistic images to represent the primary objects of interest in a scene may increase recognition time (for non-trivial features) because of the absence of subtle visual cues present in real scenes. Secondly, if such simple techniques are used to render the background or peripheral features, the extraneous high-frequency artifacts arising from sharp edges, and related aliasing effects distract attention from the primary focus. The challenge of realistic image reconstruction, then, is to find ways of reproducing, at reasonable cost, visually acceptable facsimiles of real scenes.

To realistically portray real-world scenes it is necessary to capture all significant visual cues that the human visual perception system uses to construct object hypotheses from visual stimuli. These cues may be classified into two categories. There are the 'macroscopic' cues such as stereopsis, perspective foreshortening, intensity-distance cuing, shadows, and hidden surface removal. Secondly, there are the 'microscopic', texture-related cues which depend on the surface material and finish of the objects. This section focuses on the latter issue: how to provide realistic representations of surface texture in a real-time application.

Solutions to the image reconstruction problem may be broken down into four approaches which span the cost-vs-realism spectrum as shown in Figure 1. At one extreme [A], we have photographic quality images obtained by digitizing high-resolution photographs of surface material types. At the other extreme [D] we have the simple polygonal representations with no surface detail found in most simulators and computerized modelling systems today. Between these two extremes we have two other approaches that represent different approaches and trade-offs in real-time synthetic image generation. Approach [B] attempts to generate the closest approximation to [A], within the real-time constraints, using texture-mapping techniques, realistic shading models etc. The third approach [C], in contrast, does not attempt to generate a microscopically-accurate equivalent of [A]. Instead, it uses knowledge about the human factors of visual perception and cognition to generate an image that appears realistic.

The main advantage of approach [A] is its high fidelity to the original, measured on an objective (i.e., photometric) basis. However, it has little practical application in real-time simulation systems. A large amount of information must be stored

to provide adequate realism at high resolutions, information which is largely invisible (i.e., unresolvable) for objects at large distances. Because of the large amounts of information that must be processed and transmitted, this approach cannot be used for dynamic real-time simulation.

Approach [B] is largely identical to approach [A], except that a real-time constraint is imposed. As a result, image quality is degraded, relative to [A]. In addition, storage constraints may limit the range of different surface material types. Because the degradation is uniform and does not exploit the strengths and weaknesses of the visual system, approach [B] typically results in a sub-optimal use of system resources.

The third approach, which is the one we propose to implement, recognizes that in a graphical simulation, what matters is not the absolute fidelity of the reconstructed image, but rather, the perceived quality of the image. Three characteristics of the visual perception system are used to determine the tradeoffs that are made in the reconstruction process. Firstly, the eye recognizes patterns and relative quantities, not absolute values. Thus, for example, we can immediately distinguish a mountain range in a scene containing other images because it possesses characteristics associated with mountain ranges, and not because it maps identically onto a previously seen real-world mountain range. Secondly, the amount of surface detail that can be resolved decreases with increasing distance from the observer. Thirdly, the sensitivity of the visual system to detail diminishes as the velocity of the viewed object (relative to the primary focus) increases.

To take advantage of the first characteristic of the eye, we plan to use a fractal based representation scheme for modelled objects. The idea is to generate synthetic features whose fractal dimension is equivalent to the fractal dimension of the real-world object it represents. In this way, the surface texture c an be made to look very similar to the real object. Secondly, because of the self-similarity (or "scale-free") property of fractals, interpolations between small-scale sample points preserve the small-scale characteristics when resolution is increased. As a result the amount of storage required for surface detail is low, and independent of the distance of the object from the observer, a crucial property not shared by the explicit representation schemes of methods [A] and [B]. Another related property of fractals is that they possess the so-called internal and external consistency. This means that the visual integrity of the simulated surface is preserved as the observer zooms in and out of the image, a property not shared by some of the simplistic texturing schemes sometimes used for polygons in method[D].

We shall exploit the third visual property to tailor the

level of detail displayed in a scene to the time that is available to observe it, taking advantage of the fact that if an images changes slowly, there is also more time to construct it.

It is our theses that under the real-time constraints of the VCDD system, approach [C] will yield results that are superior to the other methods, given the same limited computing resources.

References

ANTE74 Antes, J.R., "The Time Course of Picture Viewing," Journal of Experimental Psychology, 1974, 103, 62-70.

FOLE82 Foley, J.D., and A. van Dam, "Fundamentals of Interactive Computer Graphics," Addison-Wesley, 1985, 431-445.

LOFT75 Loftus, G.R., and S.M. Bell, "Two Types of Information in Picture Memory," Journal of Experimental Psychology: Human Learning and Memory, 1975, 1, 103-113.

LOFT79 Loftus, G.R., and H.L. Kallman, "Encoding and Use of Detail Information in Picture Recognition," Journal of Experimental Psychology: Human Learning and Memory, 1979, 5, 197-211.

NELS74 Nelson, T.O., J. Metzler, and D.A. Reed, "Role of Details in the Long-term Recognition of Pictures and Verbal Descriptions," Journal of Experimental Psychology, 1974, 102, 184-186.

PASN85 Pasnak, R., and Z.E. Tyer, "Distinctive Local Features of Visual Patterns," Bulletin of the Psychonomic Society, 1985, 23, 113-115.

PASN86 Pasnak, R., and Z.E. Tyer, "Complex Local Features as Determinants of Pattern Discrimination," Bulletin of the Psychonomic Society, 1986, 24, 41-43.

YARB67 Yarbus, A.I., "Eye Movements and Vision," New York, Plenum, 1967.

## 5.0. Overall Methodology

The computational requirements of the VCDD are very stringent, especially because the scenes must be generated in real time in response to operator interaction. For this reason it is necessary to adopt a methodology which attempts to minimize on-line real time computing load on the VCDD system. To achieve this we have adopted two strategies. First we partition the overall task into off-line and on-line sub-tasks. Our objective is to minimize the on-line computing requirements. Secondly, the additional on-line computing needs have been prioritized and organized in a hierarchical fashion. Consequently, we are able to achieve a dynamic trade-off between image quality and available computing resources. For example, if the scene is changing slowly then the additional computing time can be utilized to improve the image quality. This strategy is supported by the perception studies presented in the previous Section.

At the outset, it is emphasized that the image reconstruction is done off-line. The output of the processing is referred to as the object database which, in turn, is the input to the VCDD (Figure 1). The use of the object database is the task of the VCDD. We visualize that it may be necessary to develop a filter which takes the object database produced and converts it to a database compatible with the VCDD. This concept would be necessary especially because in the initial stages the VCDD may not be able to handle all the information included in the object database produced by the image reconstruction system.

Since the image reconstruction system is off-line it is possible to utilize techniques that are more complex. We believe that this approach will lead to more realistic scenes. In our approach we have tried to focus on ensuring consistencies between different parts of the scene and between the time sequence of scenes.

The input to the image reconstruction algorithms is the Digital Landmass Systems (DLMS) database. This database has in turn been divided into two databases - Digital Terrain Elevation Database (DTED) and Digital Feature and Acculturation Database (DFAD). The DTED and DFAD databases are available at two levels of resolution referred to as Level 1 and Level 2. More details of the database content are available in [DMA86], and a summary of the main points is included in Appendix A.

For purposes of our analysis the DLMS database is viewed as being divided into two parts the features database and the non-features database. Obviously the DTED database is a non-feature database, but in this category we also include the part of the DFAD database that provides details regarding the Surface Material Category(SMC). The 12 SMC classes are identified in the

appendix. These classes provide gross characteristics of the point, linear and areal elements in the scene.

The image reconstruction methodology can be divided into the following steps:

(1) Choose significant features.
(2) Formulate the features in terms of a small set of primitives.
(3) Form the objects in the scene.
(4) Assign texture to the object surfaces to make the objects more realistic.
(5) Use graphics techniques to develop the perspective view of the scene as composed of the objects identified above.

## CHOOSE SIGNIFICANT FEATURES

The features to be incorporated in the image are of three kinds - point, linear and areal. The features included in the scene will vary depending on the nature of the terrain and whether we are dealing with urban or rural scenes. The choice of features is restricted to those identified in the DFAD database. It is noted that there is a very large variety of features that should be included in the database according the DFAD specifications. However, it is not always possible to distinguish one type of feature from another.

## FORM FEATURES USING PRIMITIVES

From the set of features chosen a set of primitives need to be defined. These primitives will form the building blocks for the construction of the features. The primitives sought are of two kinds. First kind of primitives are block oriented representing solid objects, and the second kind of primitives are representation of surfaces. While the first kind of primitive will be utilized for representing the solid features in the DFAD database, the latter primitive would be utilized for characterizing the terrain surface.

## CHARACTERIZE AND CONSTRUCT OBJECTS FOR THE OBJECT DATABASE

The output of the image reconstruction system is the definition of the objects to be included in the object database. These objects are characterized in terms of the primitives identified above. The solid primitives are identified in terms of the size, location and surface characteristics. The terrain primitives are identified in terms of the type of surface, location of the surface, size of the surface, and texture of the primitive. It is emphasized that the solid primitives can be directly determined from the DFAD database by using the following sequence: extract the significant features from the database, formulate features in terms of the primitives. This is a direct

result of the fact the DFAD database contains an explicit definition of all the features included in the database. On the other hand, the identification of the terrain primitives is much more difficult.

In graphics research terrain is usually synthetically generated. However, in our approach the DTED database only provides a definition of elevation at discrete points of the scene, but does not identify the kind of surfaces to fit. Moreover we have to perforce contend with the presence of noise in the measurements and elevation estimates included on the DTED database. For these reasons the identification of the terrain primitives in the scene is a much more computationally complex task. This task can be formulated in the following way: segment the scene into smaller uniform regions where uniformity implies that the same surface can fit each smaller region with a low error rate. This is a complex analytical and computational problem. This is an area of research and uncertainty, for this reason we have devoted Section ... to a study of this problem and have then suggested a detailed algorithm t perform this task.

## REALISTIC OBJECT SURFACES

As noted above both for solid primitives and terrain primitives the surface characterization is rather important. How the surface should be characterized is another area of research. Several approaches have been explored in this regard. For example, one approach would be to take photographic samples of the textures of interest. (Such samples are readily available in the photographic literature.) The problem with this approach is that if the same pattern is repeatedly utilized in the scene then the viewer can usually spot the repetitive nature and this may in turn distract from the task assigned to the user. To minimize this repetition we need to develop a large database of the textures and avoid using the same section of the texture. These considerations inevitably lead to large secondary storage requirements, more computational complexity and more difficulty in meeting the real-time requirements.

We prefer to utilize a scheme in which the texture is created on-line during the final scene generation. Further the technique should be responsive to hierarchy of representation. For the point, linear, and areal features and the terrain primitives we propose the use of fractals. A review of the approaches for fractals in this application is given in Section 7. In that Section we also suggest an approach to the generation of the primitives.

## SCENE RECONSTRUCTION

The final scene reconstruction is very hardware dependent. Much of this task has been included in the VCDD system. The

reconstruction is dependent on the users position. In the VCDD, several mechanisms have been simulated to control the viewers position, direction and field of view. For each observer, those objects currently in the field of view are extracted from the database.

Of course, all the objects in the field of view may not be visible from the viewer's current position. High speed methods have to be utilized to generate visible objects in the scene. By using extent testing and binary space partitioning, one can substantially reduce the computational processing for visible object determination. Finally, the scene is displayed and the z buffer in the IRIS removes the remaining hidden lines.

References

[DMA86] Defense Mapping Agency Product Specifications for Digital Feature Analysis Date (DFAD) - Level 1 and Level 2, April 1986.

## 6.0. Surface Reconstruction

The surface reconstruction is required to reconstruct the surface of the ground from the supplied data. The procedure for surface reconstruction starts with a segmentation process that will separate one soil group from the others. Since, the elevation data for each region is given, a number of surface reconstruction algorithms for range data images can be used. A number of algorithms that have been suggested for surface reconstruction using depth data (distance from the observer) will be reviewed in sections 2, 3, 4, and 5. Thereafter we will suggest a comprehensive algorithm which would be suitable for our application.

## 6.1. Simple Patches

Surface approximation using simple patches is one of the important surface representation approaches in computer graphics applications. The earliest approaches used approximation by planar patches, later methods have used other surface patches such as two dimensional splines. The number of patches found is typically very large and the points and lines, where the approximating patches are joined, need not have any significance. An example of using surface patches proposed by [5] is given below.

An algorithm for reconstructing 3-D objects using range data has been developed by Vemuri and Aggarwal [5]. Their algorithm proceeds as follows:

A) The 3-D (x,y,z) coordinates of the range data points are stored in three arrays. These arrays are partitioned into overlapping windows of size K (overlap is chosen to be 2 columns/rows).

B) The standard deviation of the Euclidean distance between consecutive points in the K X K neighborhood is found. This gives an indication of the scatter in the data. If this standard deviation is larger than a threshold the window is discarded, else a surface is fitted to the K X K window. The surface fitting is done using splines under tension.

C) Next step in the algorithm is to find all those points that fall on edges in the scene. This is achieved by computing the Principle Curvatures at points in the patch and if the principle curvature is greater than a threshold, the point is classified as an edge.

## 6.2. 3-D Surface Characterization

The term surface characteristic refers to a descriptive feature of a general smooth surface. Surface characterization refers to the computational process of partitioning surfaces into regions with similar characteristics. The descriptive quality of the features used to identify surfaces is of critical importance to the surface description process. The methods to characterize surfaces can be viewed as being in two sub-classes. The first describes the surfaces by point wise properties whereas the other attempts to derive global description. An example of using 3-D surface characterization will be given next.

An approach to range image description using the Mean Curvature (H) and Gaussian Curvature (K) is proposed by Besl [2]. H and K are identified as the local second order surface characteristics that posses several invariance properties and represent extrinsic and intrinsic surface geometry respectively. The signs of these surface curvatures are used to classify the image surface regions into one of eight basic types.

Differential geometry suggests that these are quite reasonable surface features to consider. These two surface curvatures are derived from the first and second fundamental forms of surfaces. The first fundamental form measures the small amount of movement on the surface at a point for a given small movement in the parameter space. This function is invariant to surface parameter changes and to translation and rotations of the surface. It depends only on the surface itself. It is, therefore, referred to as intrinsic properties of a surface. The second fundamental form measures the correlation between the change in the normal vector and the change in the surface position at a surface point as a function of a small movement in the parametric space.

The sign of the Mean and Gaussian Curvature yield eight basic Gaussian Surface types, as shown in Table (6.1).

| | | K + | K 0 | K - |
|---|---|---|---|---|
| H | - | Peak | Ridge | Saddle Ridge |
| H | 0 | - | Flat | Minimal Surface |
| H | + | Pit | Valley | Saddle Valley |

Table 6.1 Sign of the Mean and Gausian Curvature

These two curvature parameters can be calculated using estimation of the Partial derivatives of a surface. They are give by [2];

$$K = f_{xx}f_{yy} - f^2{}_{xy}/\ (1+f^2{}_x+f^2{}_y)^2$$

$$H = f_{xx}+f_{yy}+f_{xx}f^2{}_y+f_{yy}f^2{}_x-2f_xf_yf_{xy}/2(1+f^2{}_x+f^2{}_y)^{3/2}$$

These two functions can be mapped into one eight level functions, known as the HK-sign map via a linear combination of the signum function. This compresses the useful surface structure information into eight levels. This substantially constrains the possibilities of visible surfaces and possesses the right type of invariance properties. Also, the sign of a second order quantity computed from data is more reliable than the magnitude because derivatives are difficult to estimate accurately from noisy digital data. There are a number of problems with the HK-Sign maps. These problems are:

1) Smoothing - Preliminary smoothing appears necessary to obtain reasonable differential geometric quantities from digital data (as will be described later). However, after filtering the HK-sign surface labels then reflects the geometry of the smoothed surface data and not the original surface data. Hence, the HK-sign pixel labeling results obtained by smoothing, derivative estimation and surface curvature computation must be further processed.

2) Unwanted connection caused by noise - In the presence of noise, HK-sign surface labels of one surface region tend to 4-connect with equivalent labels of neighboring, but distinct, surface regions. It is generally not correct to simply isolate a 4-connected region as a meaningful image surface.

3) Global surface properties lacking - Explicit symbolic representation of a surface that possess global surface shape properties is required.

Besl [2] suggested the following procedure to compute the HK-sign Map:

1) Pre-smoothing the range image using a Gaussian window.

2) Compute the partial derivatives using the window convolution technique (the facet model) .

3) Compute the H and K using the relations given above.

4) Smooth the curvature values using another (smaller window) Gaussian smoothing filter.

5) Threshold the curvature values obtained.

The HK-sign map and the original image are used as inputs to a segmentation algorithm that will group the HK-sign labels into global surfaces which will be represented by a parametric equation. The algorithm is composed of the following steps:

(1) <u>Seed Region Extraction</u> - The algorithm begins by considering the HK-sign map. The largest connected region of any fundamental HK-sign surface type in the image is isolated using the following strategy:

A - Compute a surface type histogram.

B - Sort the histogram on the basis of frequency of occurrence of surface types.

C - Compute the connected components of the surface type with the largest histogram pixel count as determined by the sorted histogram and isolate the largest region.

D - Compute the connected components of the next largest surface type in the sorted histogram. Isolate the largest connected region. Repeat this process until a surface type is reached that has a pixel count less than the largest connected region encountered so far for a particular surface type.

This approach reduces the computations required by a brute force method. It takes the advantage of the fact that the number of pixels in the largest connected component region of that type can never by larger than the number of pixels of that type in the image. The largest component obtained above is contracted using a 3X3 window. This contraction process helps in finding a far enough inside the boundaries isolated region which has escaped the undesirable side effects of smoothing and derivative operations used in the computation of surface curvature.

The largest connected sub-region with the minimum number of pixels greater than or equal to lower threshold is assigned to be a seed region. The lower threshold must be greater than or equal to the minimum number of points required for the simplest surface fit (described next).

(2) <u>Surface Fitting and Region Growing</u> - Each isolated seed region, obtained in the first step is given as the input to the iterative region growing algorithm which is based on variable order surface fitting. First order, second order, and fourth order bivariate polynomials are proposed by Besl [2] as the set of approximating functions for HK-sign surface primitives.

A plane is always fitted first to the small region using

least squares approach. If the seed region belongs to a surface that is not too highly curved a plane will fit quite well to the original digital surface. If the plane fits the seed region to within a maximum error threshold, then the seed is allowed to grow. If not, the seed is fitted with the next higher - order surface and the algorithm proceeds similarly. If all three fit orders were tried and the error was never less than the threshold, the seed region is rejected and then continuing by looking for the next largest connected region of any surface type.

After a surface is fitted to a region, the description is used to grow the region into a larger region where all the pixels in the larger regions are connected to the original region are compatible with the approximating surface function for the original region. The unmarked connected components of the HK-sign map are considered sequentially as ranked by region size. For these regions the fit error threshold are doubled. Surface regions with fit errors beyond the new error threshold are rejected.

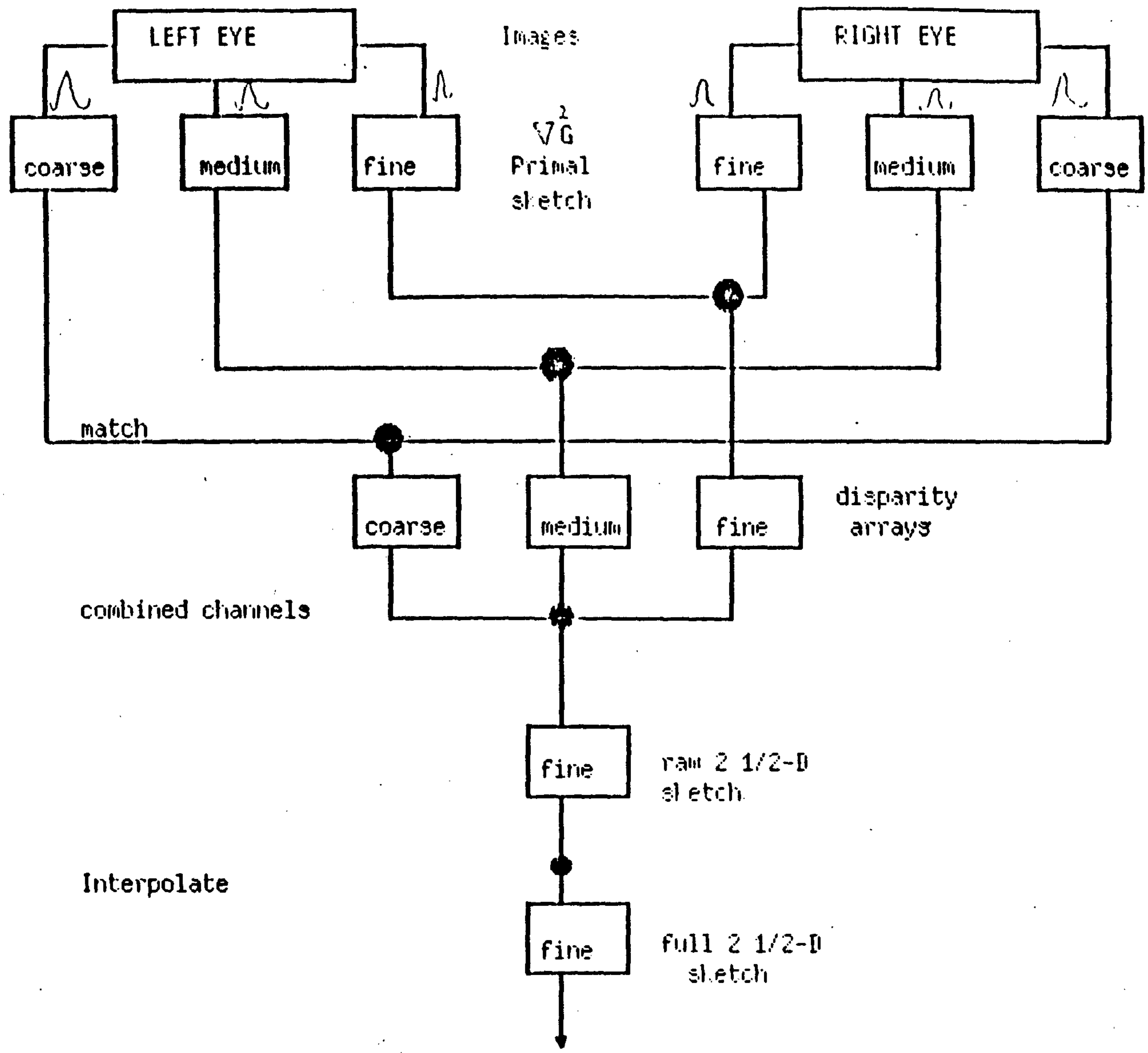
If surface curvature estimates can be improved, the initial HK-sign map segmentation will be improved, which could reduce the effort required by the iterative region growing algorithm. Scale space technique [1,6] may also be used to improve the HK-sign map. This could be achieved by smoothing the image with a number of Gaussian smoothing filters with different standard deviation and then group the pixels from different levels using scale space tracking techniques [6].

## 6.3. Single Level Approach

Grimson [3] pioneered the mathematical theory of visual surface reconstruction process which transforms the sparse surface description, obtained from stereo algorithm, into complete description. The output of the stereo algorithm, to within a particular resolution, constitutes a complete representation of a surface. The human system requires and constructs a more specific, finer resolution representation of surface. Grimson discussed the sufficiency of the stereo representation from psychophysics, computational needs, and application viewpoint.

The stereo module with single-level surface reconstruction is shown in Fig (6.1), (three channels are shown for simplicity). This is based on the theory of early vision described by Marr [7]. Grimson proposed that before reconstruction begins, the multiple, sparse depth representations output through the different bandpass channels be combined into a single raw 2 1/2D sketch in a way which maintains consistency across all scales. The raw 2 1/2D sketch then contains sparse depth information at the finest resolution possible. Next a single reconstruction process operating at this final level

Figure 6.1 The Stereo Module with Single-Level Surface Reconstruction



generates a unique full 2 1/2D sketch representing depth information at high resolution.

The surface reconstruction problem could be described as follows. Suppose we are given a set of known depth points - we want a method for finding a surface to fit through these points that is most consistent with the surface consistency constraint. The surface consistency constraint states that between known depth values, the surface cannot change in a radical manner, since such changes would usually give rise to additional depth points. Grimson suggested two ways to find the most consistent surface. In the surface interpolation problem we construct a surface that exactly fits the set of known points. The other way is to find the surface that approximately fits the known data and to ensure smoothness properties in some sense.

The problem could be formulated mathematically as follows:

A) Measure of the surface curvature: For any point on the surface, consider the intersection of the surface with a plane containing the normal to the surface at that point. This intersection defines a curve, and the curvature of that curve can be measured as the arc-rate of rotation of its tangent. As the normal section is rotated through 2 radians, all possible normal sections will be observed. There are two sections of particular interest, that which has the maximum curvature and that which has the minimum. The directions of these sections are orthogonal. These directions are the principal directions and the curvatures of the normal sections in these directions are then the principal curvatures, denoted Ka and Kb. It can be shown that the curvature of any other normal section is defined by the principal curvatures.

There are two standard methods for describing the curvature of the surface, in terms of the principal curvatures($K_a$,$K_b$). One is the first (or mean) curvature of the surface

$$J = K_a+K_b \quad \text{\_\_\_\_\_} \quad (1)$$

The other is the second or Gaussian curvature of the surface

$$K = K_a-K_b \quad \text{\_\_\_\_\_} \quad (2)$$

For a surface defined by the vector (x,y,f(x,y)), these curvature are given by

$$J = \partial/\partial x\ (f_x/(1+f_x{}^2+f_y{}^2)^{1/2} + \partial/\partial y\ (f_y/(1+f_x{}^2+f_y{}^2)^{1/2} \quad \text{\_\_\_\_} \quad (3)$$

and

$$K = f_{xx}f_{yy}-f^2{}_{xy}/(1+f_x{}^2+f_y{}^2)^2 \quad \text{\_\_\_\_\_} \quad (4)$$

There are two possibilities for the surface function. One is to measure the mean curvature of the surface,

$$Q_1(f) = \{\iint J^2 dxdy\}^{1/2} \quad \text{\_\_\_\_\_\_} \quad (5)$$

Assuming that $f_x$ and $f_y$ are small, the above function can be approximated by,

$$Q_1(f) = \{\iint (D^2 f)^2 dxdy\}^{1/2} \quad \text{\_\_\_\_\_\_} \quad (6)$$

A second possibility for reducing curvature is to reduce the Gaussian curvature,

$$Q_2(f) = \{\iint K^2 dxdy\}^{1/2} \quad \text{\_\_\_\_\_\_} \quad (7)$$

Using the above assumption of small $f_x$ and $f_y$ reduced to ,

$$Q_2(f) = \{\iint f_{xx} f_{yy} - f^2_{xy} \, dxdy\}^{1/2} \quad \text{\_\_\_\_\_\_} (8)$$

B - Quadratic Variation - If the quadratic variation of the surface is considered the problem could be formulated as follows,

$$Q_3(f) = \{\iint (f^2_{xx} + 2f^2_{xy} + f^2_{yy}) dxdy\}^{1/2} \quad \text{\_\_\_\_\_\_} (9)$$

The three functions $Q_1(f)$, $Q_2(f)$ and $Q_3(f)$ are valid representation of the surface reconstruction problem. It can be shown, that using the above representation, a unique surface exists [3]. It can also be shown that the best approximation can be achieved using $Q_3(f)$.

Algorithms for solving the optimization problem both in the case of interpolation (the surface passes exactly through the data) and in the case of approximation (the surface passes near the data) are given in Grimson [3]. The algorithms could be applied to any of the three functions given earlier. The application of the algorithm to $Q_3(f)$ will be given next.

Since any function minimizes $Q_3(s)$ also minimizes $Q^2{}_3(s)$ one may consider the function

$$Q(s) = \iint (s^2_{xx} + 2s^2_{xy} + s^2_{yy}) \, dxdy \quad \text{\_\_\_\_\_\_} \quad (10)$$

where s denotes a surface.

The continuous function must be converted to a discrete grid. Assuming a grid of size mxm, each point on the grid may be represented by its coordinate location, so that the points (i,j) correspond to the grid point lying on the ith row and the jth column. At each point(i,j) on the grid, a surface value may be represented by s(i,j). These variables may be considered as a vector of variables denoted by s = {s(0,0), s(0,1) ---, s((m-1),(m-1))}. The partial derivatives may be approximated by

$$\frac{\partial^2 s(i,j)}{\partial x^2} = \frac{1}{h^2}\,[s(i+1,j)-2s(i,j)+s(i-1,j)] + O(h^2) \qquad (11)$$

$$\frac{\partial^2 s(i,j)}{\partial y^2} = \frac{1}{h^2}\,[s(i,j+1)-2s(i,j)+s(i,j-1)]+O(h^2) \qquad (12)$$

$$\frac{\partial^2 s(i,j)}{\partial x \partial y} = \frac{1}{4h^2}[s(i+1,j+1)-s(i+1,j-1)-s(i+1,j-1)+s(i-1,j-1)] + O(h^2) \qquad (13)$$

Converting the double integral to discrete equivalent, the discrete objective function is given by;

$$Q(s) = \{ \text{minimize} \sum_{i=1}^{m-2} \sum_{j=0}^{m-2} (s(i-1,j)-2s(i,j)+s(i+1,j))^2$$

$$+ 2 \sum_{i=0}^{m-1} \sum_{j=1}^{m-2} (s(i,j-1)-2s(i,j) + s(i,j+1))^2$$

$$+ 2 \sum_{i=0}^{m-2} \sum_{j=0}^{m-2} (s(i,j)-s(i+1,j)-s(i,j+1)+s(i+1,j+1))^2 \} \qquad (14)$$

Finally, the characterization of the constraints will be considered for the interpolated surface and the approximated surface.

A - <u>Interpolation Algorithm</u> - The gradient projection method could be applied to the interpolation problem as follows:

minimize $Q(s)$

subject to $s(i,j)-c(i,j)=0 \quad \forall (i,j) \quad L$

where $c(i,j)$ are the stereo data.

and for L=(i,j) there is a known depth value at the grid point (i,j).

The algorithm then starts by determining a feasible initial surface approximation. The gradient function of the function is obtained and the surface approximation is refined until the magnitudes of the surface is smaller than some threshold.

B - Approximation Algorithm - The basic notion in this case is to combine a measure of "nearness of fit to the known points" with a measure of the consistency of the surface with the information. This can be accomplished by considering a penalty method unconstrained optimization problem. Here, the objective function to minimize is,

$$Q(s) = \iint (s^2_{xx}+s^2_{yy}+2s^2_{xy})\,dxdy + B\sum_{L}(s(x,y)-c(x,y))^2$$

The effect of this objective functions is to minimize a least-squares fit through the known points, scaled relative to the original minimization problem. The constant B is a scale parameter to be determined by the degree of desired fit.

Translating this problem into image domain gives:

$$\text{minimize} \sum_{i=1}^{m-2}\sum_{j=0}^{m-1}(s(i-1,\ j)-2s(i,j)+s(i+1,j))^2$$

$$+\sum_{i=0}^{m-1}\sum_{j=1}^{m-2}(s(i,j-1)-2s(i,j)+s(i,j+1))^2$$

$$+2\sum_{i=0}^{m-2}\sum_{j=0}^{m-2}(s(i,1)-s(i+1,j)-s(i,j+1)+s(i+1,j+1))^2$$

$$+B\sum_{L}((s(i,j)-c(i,j))^2$$

The conjugate gradient method could be applied to solve the above problem.

Although, Grimson phrased the problem in terms of zero crossings obtained from images convolved with Laplacian filters, the surface reconstruction approach can be applied to any surface reconstruction which contains explicit information only

at sparse points. The only constraint is that the surface should vary as little as possible between the known surface points. Thus, whether those known points correspond to zero-crossings, edges, or some other basic description of image changes, the surface interpolation algorithm should construct the surface which minimizes variations in the surface between known points.

### 6.4. Multi-level Approach

Terzopoulos [4] proposed a multilevel approach to surface reconstruction. The speed efficiency of this algorithm is dramatically superior to that of single level reconstruction schemes. Order-of-magnitude improvements are typically observed for surface reconstructed from information provided by stereopsis. On the other hand, the expense in space in maintaining all the coarser representations is only a fraction of that required to maintain the finest one. Fig (6.2) illustrates the multilevel surface reconstruction scheme and its incorporation into stereopsis. The multilevel scheme involves both intralevel processes which propagate information within a representation, as well as interlevel processes which communicate between representation. The interlevel processes are further classified into those which transfer information from coarser levels to finer ones, and those which transfer information from finer levels to coarser ones. The mathematical foundations of a multilevel approach to visual reconstruction in the context of stereo vision will be given next.

Visual surface reconstruction can be characterized formally as a constrained optimal approximation problem in two dimensions. In the context of stereo vision, where constraints embody depth measurements to surfaces in the scene, the goal is to reconstruct, as accurately as possible, the shape of the surface which gave rise to these measurements. The constraints provided by the stereo computation are never completely reliable. Errors due to noise and errors in matching corresponding zero-crossing are bound to occur. This suggests that the data should not be interpolated directly. This turns the problem into one of surface approximation to the given data. A treatment for the problem using the physical model shown in Fig (6.3) is given below. Consider a planar region M, the region within which we wish to obtain an optimal approximating surface most consistent with a finite set of sparse constraints. Let us imagine that the constraints comprise a set of vertical pins scattered within M, the height of an individual pin being related to the distance from the viewer to the surface in the scene. Suppose that we take a thin flexible plate of elastic material that is planar in the absence of external forces, and constrain it to pass near the tips of the pins by attaching ideal springs between the pin tips and the surface of the plate as shown in Fig 6.3. In its equilibrium state the thin plate

Figure 6.2 Multi-Level Approach to Surface Reconstruction

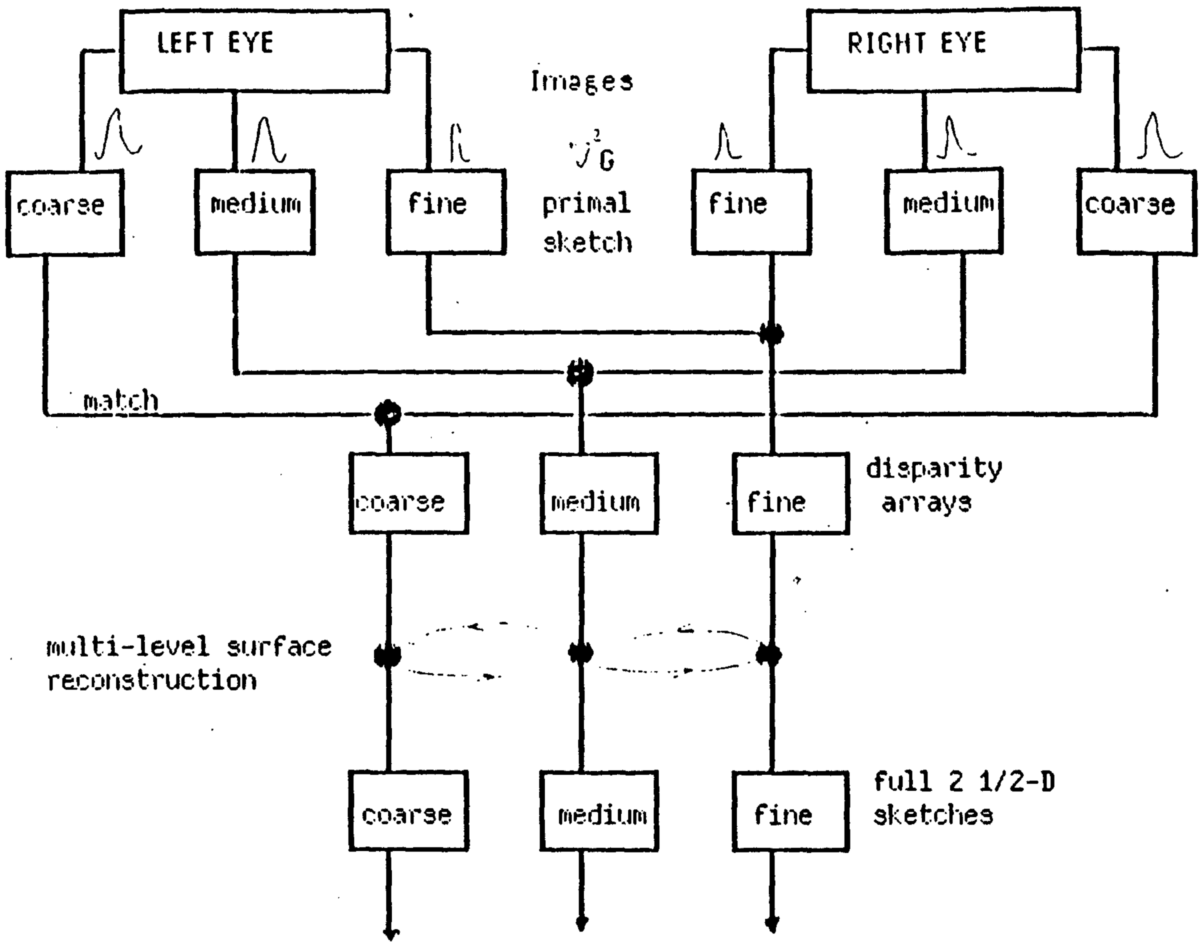
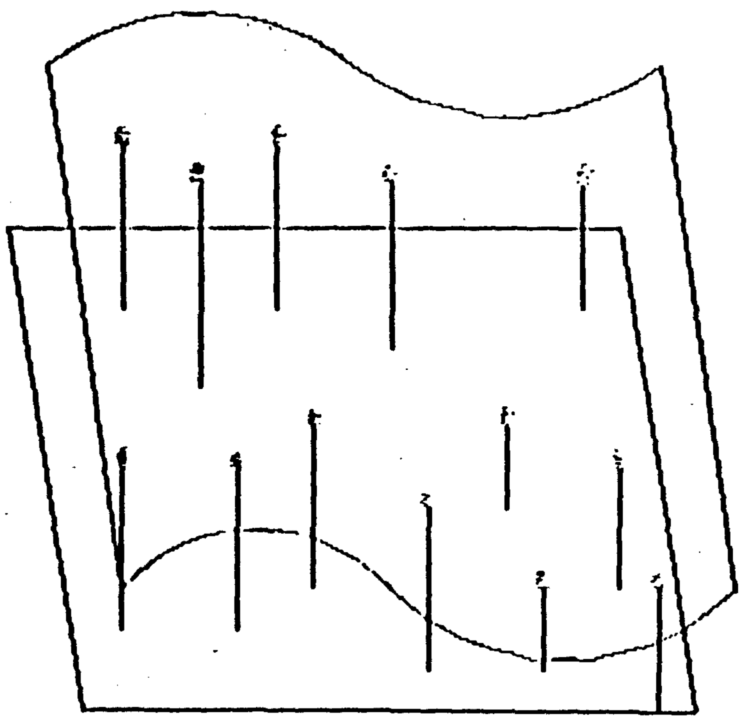


Figure 6.3 The Physical Model for Surface Approximation



will trace out a fair approximating surface, and that this surface will be smooth in between constraints. Using the above physical model the problem could be characterized mathematically using the minimum potential energy principle from classical mechanics, which states that the potential energy of a physical system in a state of stable equilibrium is a local minimum. For the model, the potential energy in question is that due to deformation of the plate and springs, as well as the energy imparted by any externally applied forces. The potential energy of deformation is given by [4],

$$E(v) = \iint_M 1/2(D_v)^2 - (1-t)(v_{xx}v_{yy}-v^2{}_{xy})\,dxdy$$
$$-\iint_M gv\,dxdy - \int_{\partial M} p(s)v\,ds - \int_{\partial M} m(s)\frac{\partial V}{\partial n}\,ds$$
$$+1/2 \sum_{(x_i,y_j)\in c} B(x_i,y_i)[v(x_i,y_i)-c(x_i,y_i)]^2 \quad \text{\_\_\_\_\_\_} \quad (1)$$

where D is the Laplacian operator.

t is the POISSON ratio, measure the change in width as the material is stretched lengthwise.

g force density applied to the surface.

P force density on the boundary.

m is the density of applied bending moments normal to the curve and $\partial/\partial n$ is the directional derivative along the outward normal to M.

The deflection of the plate at equilibrium is that function u from a set V of admissible functions v, for which the potential energy E(v) is minimal. A numerical approach to the variational principle problem, stated above, using the finite-element method is suggested by Terzopoulos [4]. The main advantage of the finite element method is its generality.

In the context of surface approximation problem, it can be applied over domains M of complicated shape, and it is not limited to uniform discretization of these domains. The variational principle problem given by Eq(1) can be transferred to the form

$$E(v) = 1/2a(v,v)-f(v)$$

where

$$a(u,v)= \iint_M DuDv -(1-t)(u_{xx}v_{yy}+u_{yy}v_{xx}-2u_{xy}v_xg)\,dxdy$$
$$+ B \sum_{(x_i,y_i)\in c} u(x_i,y_i)v(x_i,y_i)$$

and $f(v) = \iint_M gv\,dxdy + \int_{\partial M} p(s)\ v\,ds + \int_{\partial M} m(s) \frac{\partial v}{\partial n}\,ds$

$$+ B \sum_{(x_i,y_i)\in C} [c(x_i,y_i)v(x_i,y_i) - 1/2c^2(x_i,y_i)].$$

Also using the necessary condition for the vanishing of the first variation we have;

$a(u,v) = f(v).$

The above problem is transferred into a discrete form using a non conforming element. This is achieved as follows: suppose that M is rectangular, and consider a uniform triangulation $T^h$ of M into identical square elements E, where the fundamental length h is the length of a side of E. The elements are considered to be interconnected at the nodes (where the nodes is vertex of an elemental square). The next step is define a space of polynomials over the element domain. A second degree polynomials could be chosen. Using the above formulation and using the concept of free plate (where it is assumed that no external force is applied to the plate) f(v) is reduced to ;

$$f(v^h) = B \sum_{(x_i,y_i)\in c} (c(x_i,y_i)\ v^h(x_i,y_i) - 1/2c^2(x_i,y_i)).$$

Also using the simplification that t=0, a(u,v) is reduced to,

$$a_n(u^h,v^h) = \sum_{E\in Th} \iint_E u^h_{xx}v^h_{xx} + 2u^h_{xy}v^h_{xy} + u^h_{yy}v^h_{yy}\,dxdy$$
$$+B \sum_{(x_i,y_i)\in c} u^h(x_i,y_i)v^h(x_i,y_i)$$

The partial derivatives can be computed using approximation similar to that given in section (3). The problem can be written in a matrix form (aside from the additive constant term) as follows:

$$E_h(v^h) = 1/2(V^h, A^h v^h) - (f^h, v^h)$$

where (.,.) is the inner product.

$$f^h = Bc^h$$

and $A^h$ is the Hessian Matrix. Hence, the minimizing vector of displacements $u^h$ satisfies the condition:

$$DE_h(u^h) = A^h u^h - f^h = 0 \qquad (2)$$

The multilevel approach to solve Eq(2) uses sparse depth information over a range of resolutions. The information at any particular scale can be thought of a set of constraints which, at that level, define a well-posed, discrete surface

approximation problem. The hierarchy of problems is then given by the sequence of L linear system (where L is the number of levels the form $A^{hk}u^{hk} = f^{hk}$ 1<k<L whose discrete solutions $u^{hk}$ define a sequence of functions which constitute the hierarchy of full surface representation.

Terzopoluos suggested an algorithm in which the hierarchy of levels cooperate, through a bidirectional flow of information, to generate simultaneously multiple, equally accurate surface representations, and do so with much less computational effort than would be expended in solving the one level in isolation. This can be accomplished by initially considering only two levels, a fine one and a coarse one. Suppose that by an iterative process we obtain an approximate solution to the coarse level system. This approximate solution is then interpolated to the fine level where it becomes the initial approximation to that level. This will be continued for the rest of the levels until an approximate solution within a certain error criteria is obtained in each level. A correction scheme is used to correct the value of the approximating function in each level.

Although Trezopolous discussed his algorithm using constraint obtained from stereo algorithm it can also be applied to other set of information.

## 6.5. Experimental Results

An experiment for the computation of the HK-sign map had been performed using the approach proposed by Besl[2]. The steps required to compute the HK-sign map was given in section (2). As discussed in section (2) the five partial derivatives of the depth map need to be estimated. A facet model which uses a local quadratic surface model is used. In this model each data point in a given NXN window is associated with a position (x,y) from the set UXU where N is odd and:

$$U = \left\{ -(N-1)/2,\ ----,\ -1,\ 0,\ 1,\ ---,\ (N-1)/2 \right\}$$

The following normalized discrete orthogonal polynomials provide the quadratic surface fit: $b_0(x) = 1/N$, $b_1(x)=3x/M(M+1)(2M+1)$, $b_2=1/\ (P(M)*(x^2-M(M+1)/3))$

where $M=(N-1)/2$

and $P(M) = (8/45)M^5+(4/9)M^4+(2/9)M^3-(1/9)M^2-(1/15)M$

These b vectors are computed and stored for any given window size. A surface function estimate f(x,y) is of the form:

$$\hat{f}(x,y) = \sum_{i,j=0}^{2} a^i{}_j .\ b_i(x) . b_j(y)$$

Minimizing the mean square error

$$E = \sum_{(x,y)\in U^2} (f(x,y)-\hat{f}(x,y))^2$$

The solution for the unknown coefficients is given by:

$$a_{ij} = \sum_{(x,y)\in U^2} \hat{f}(x,y).b_i(x).b_j(y)$$

The partial derivatives are then given by:

$f_x = a_{10}$ , $f_y = a_{01}$ , $f_{xy} = a_{11}$, $f_{xx} = 2.\ a_{20}$, $f_{yy} = 2.a_{02}$

Using the above technique for estimating the partial derivatives the computational process for calculating the HK-sign map is as follows:

1) Pre-smoothing the range image using a Gaussian window (11X11)

2) Compute the partial derivatives using the window convolution technique describe above with N=7.

3) Computer the H and K using the relations given in section (2).

4) Smooth the curvature values using a Gaussian smoothing filter (7X7).

5) Threshold the curvature values obtained.Some experimental results using the above procedure is given in Fig (6.4).

As can be seen from Fig (6.4) the maps do not correspond to surfaces in the input range data and then it must be refined.

Besl used the algorithm described in section (2) to obtain his final surface description. If the quality of the surface curvature estimation can be improved, the initial HK-sign map segmentation will be improved. This can be achieved by improving the estimation of the partial derivatives, improve the range finders to yield better depth resolution, or a multi-scale technique for computing the curvature parameters.

The multi-scale technique [1,6] starts with a number of smoothing Gaussian filters of different variances. The different sizes of the filters gives curvature at different scales. The curvature in different scales are then tracked using a scale tracking technique to obtain the final curvature. This technique reduces the smoothing and the noise effect on the HK-sign label.

Figure 6.4 Experimental Results

## 6.6. Recommended Approach

The recommended approach could be based on Besl approach with the curvature labels calculated using the multi-scale technique. The height information in the data base can be used to obtain a range data image which will be used as input to the algorithm. The algorithm could proceed as follows:

1 - Since the height information will be given for a large area the range data obtained using this height information will not be dense. Also the height information will not be accurate, to some extent, in most cases. This suggests that the quality of the range data should be improved. This can be achieved using Grimson or Terzopoulous (section (2) and (3)) approach for surface reconstruction. These approaches are not sensitive to incorrect data values. Also each pixel could be divided into regions to improve the resolution of the data. The missing depth values in these new regions will be estimated using one of the above two approaches.

2 - Each point in the range data obtained in step (1) will be classified to one of the eight HK-sign labels described in section (2). The labels will be obtained using a multi-scale technique where a number of smoothing filters is used to obtain the HK-sign labels in different scales. This will improve the quality of the HK-sign map and reduce the effort required in the surface fitting algorithm.

3 - The HK-sign labels obtained in the previous step will be the input to variable surface fitting algorithms. This will transfer the data into a number of surface patches. This will reduce the storage required for the input data and allowed a real time processing since these surface patches could be obtained in advance and stored for real time displaying. The surface fitting will make use of the labels obtained in second step. The points of similar labels will be grouped together and a surface is fitted to this area. The surface order will depend on the type of the surface label. The patch will be allowed to grow if the fitting error is less than a predetermined threshold value.

## References

1) H. ASADA and M. BRADY, "The curvature Primal Sketch", IEEE Trans on Pattern Analysis and Machine Intell, Vol. PAMI-8, No. 1, Jan. 1986.

2) P. BESL, "Surfaces in Early Range Image Understanding." Ph.D., Dissertation, Electrical Engineering and Computer Science Department, University of Michigan, Ann Arbor,1986.

3) W. GRIMSON, "From Images to Surfaces," MIT PRESS,1981.

4) D. TERZOPOULOS, "Multilevel Reconstructive of Visual Surfaces: Variational Principle and Finite-Element Representatives. in multiresolution image processing,1983.

5) B.C. VEMURI and J.K. AGGARWAL, "3-dimensional Reconstruction of Objects from range data," Proc, IEEE Pattern Recognition Conf. 1984, PP 752.

6) T.J. FAN, G. MEDIONI and R. NEVATIA, "Description of Surfaces from Range Date Using Curvature Properties," Proc. IEEE, CVPR, 1986.

7) D. MARR,and T. POGGIO, "A Theory of human stereo vision, "Proc. R. Soc. Lond. B 204,1979,PP 301.

## 7.0. Fractal Analysis in Cartographic Generalization

The world of classical geometry is usually inhabited by objects of integer dimension: Spheres, cubes, and other solids are three dimensional; squares, triangles, and other plane figures are two dimensional; lines and curves are one dimensional; points are zero dimensional. The size of classical objects are measured by volume, area, length, which reflect their fundamental physical characteristics.

But, in the real world, many objects in nature have a dimension between two whole numbers. That is, their dimensionalities are fractional numbers instead of integers. These phenomena have been classified into a new theory -- fractals: objects that do not conform to classical definitions of dimension.

Fractals arise in many parts of the scientific and mathematical world. Fractal geometry is a tool to describe erratic, complex forms of nature which are neither points, lines, or areas in the world. Sets and curves with the discordant dimensional behavior of fractals were introduced at the end of the 19th century. Until now, their use has been limited primarily to theoretical investigations in advanced mathematical analysis.

The theory of fractional dimensionality was concluded by Benoit B. Mandelbrot in a systematic and nontechnical way in a book entitled "Fractals: Form, Chance and Dimension," published in 1977. Mandelbrot shows how these classic examples of fractals provide insight into a host of scientific observations previously lacking a unified theory. According to Mandelbrot, a fractal is by definition a set for which their natural dimension strictly exceeds the topological dimension. In other words, fractional dimensionality means that the Euclidean dimension that normally characterizes a form (1 for lines, 2 for areas, 3 for volumes) represents only the integer part of the actual dimension of the form, which is a fraction. Geographic lines (e.g., rivers, contours, roads, and coastlines) will tend to have different fractal dimensions depending on their geographical shape.

The calculation of the fractional dimensionality can be shown by an example. Suppose that a particular line's length is measured using two different sampling intervals X1 and X2, and there are N1 and N2 such intervals respectively. Then Mandelbrot defines the fractal dimension of the line as:

$$D = \log(N_1/N_2) / \log(X_2/X_1).$$

If the line being measured is straight or a smooth curve,

then, when the sampling interval is halved, the number of intervals will double. The ratio D will be 1.0, the conventional dimension of a line. But for an irregular geographic line, the number of intervals will tend to more than double and D will be greater than 1.0 and less than 2.0. The value of D, which is between 1 and 2, reflects the irregularity of a geographic line. As D increases towards the upper value of the range, the line becomes highly complex and intricate and the process associated with the line is space-filling.

Another important characteristic of the fractal theory is self- similarity. Most fractals in nature are invariant under certain transformations of scale. A fractal invariant under ordinary geometric similarity is called self-similar. So self-similarity can be defined as a property of certain curves where each part of the curve is indistinguishable from the whole.

One consequence of self-similarity (for coastlines and for some other phenomena as well) is that length no longer provides an adequate measure of size, for if a coastline is measured with shorter and shorter measuring sticks, its length grows without bound. In fact, every one of a half-dozen reasonable definitions of the length of a coast leads to the conclusion that the true length is infinite -- because the extent of wiggling is too great. Even though a coastline, being a curve, is geometrically one-dimensional, the method of measurement appropriate to one-dimensional objects is ineffective.

The concept of fractals is being widely used in several cartographic procedures such as line enhancement, surface generation, generalization, interpolation and error estimation. In the next section, several methods for fractal dimension analysis will be introduced and the general conclusion will be given for our approach on DLMS Data Base.

## 7.1. Overview of Some Fractal Analysis Methods

### (1) J. C. Muller's method

Line generalization is a routine task in cartographic work. In the Cartographic Journal, Muller investigated the effect of cartographic generalization on the fractal dimension of geographic lines. Generalization here means applying various generalization operations to the original map. The operations might be line enhancement, reproduction, simplification, and elimination.

Muller's approach is based on the work of Mandelbrot that the fractal dimension of a geographic line can be calculated using the formula $D = Log(N) / Log(1/r)$, where N is the number of segments used to measure the length of the line, and r is the

length of each segment (suppose we have the line of unit).

But, the real geographic lines are not made up of a series of consecutive equal line segments, and a calculation of their real length is probably meaningless since they are irregular. The length of their digital representation is nonetheless finite and provides the basis for an estimation of fractal dimension. So the empirical analysis method could be used to estimate the fractal dimension of a given geographic line.

The analog picture of a geographic line on a map or an airphoto can be digitized and described by a series of points joined by straight segments. Although, theoretically, the observed dimension will tend towards the true dimension when the interval between two consecutive points becomes sufficiently small for self-similar curves, an interval smaller than the smallest separation between two points of the digital representation of a geographic line would bias the measurement of D toward a straight line.

Usually the joints between sampling intervals walking along the line will not correspond to the digitized points. Thus, the digital line, which is a generalized representation of reality, is being further generalized through the sampling process. Obviously, the number of points describing the line and the length of the sampling interval will have a strong effect on the results of fractal dimension analysis.

A line generalization process can be realized using the fractal generator where the fractal dimension is similar to the D value of the line estimated by empirical method. The results show that only a sampling interval of length equal to the generator's unit length will provide the theoretical dimensionality.

Seven coastlines, two lake shores and one river were selected for the experiment. They are located in different places of the United States and Canada, and show a wide range of visual complexity, from few convolutions to highly complicated patterns. They were digitized at various scales, and sampled at various interval lengths.

All tested lines show some relationship between length and sampling interval. For the same range of sampling intervals, seven of the ten lines tested show a clear reduction of fractal dimension on small scale representations.

Two lines produced by different quadratic generators may appear to be very different. Although their fractal dimension might be similar, perceptually one line may be much more convoluted than the other. This small example reinforces the idea of a substantial amount of fractal distortion introduced by the

process of cartographic generalization.

Another observation of the experiment is that for large scale representations, the majority of the tested lines were found to be statistically self-similar. On small scale representations, however, the majority of the tested lines became statistically non-self-similar. It is clear that the quality of manual generalization, from the point of view of fractal geometry, varies widely.

The observed lowering of fractal dimension along with scale reduction and the concurrent change of statistical self-similarity into non-self-similarity raise serious questions regarding the integrity of the cartographic representations at small scales.

Although the scale reduction, generalization and concurrent simplification of a line did not always produce these kinds of alterations, these phenomena are reflections of distortions in the relationship between the various elements and subelements which describe the structural characteristics of a line.

One of the common denominators for guiding the implementation of generalization algorithm could be the preservation of fractal dimension. But the biggest issue is whether a generalization algorithm could be implemented which would recognize the basic patterns of a line and would reproduce those at different scales.

(2) Geoffery H. Dutton's Method

Suppose someone tried to survey a section of coastline and calculate its length and map it. Suppose the coastline has the characteristics that there is much more irregularity in the lower part of the coast than in the upper part. This may be due to the former being composed of rock outcroppings and the latter being a sandy beach.

Trying to express this property of coastline by mathematical methods, one finds scientific vocabulary confusing and inadequate. Literature in traditional geography and image processing do not have appropriate measures to deal with the irregularity objects in nature. Fortunately, foundations for such a vocabulary and for such measures have been developed.

A suitably general approach to quantifying the complexity of irregular forms, and one that directly confronts the dilemmas of Euclidean measurement, is the theory of fractals. The phenomena that Mandelbrot addresses -- natural forms arising from forces such as turbulence, curdling, Brownian motion, and erosion -- have at all scales two related properties: self-similarity and fractional dimensionality.

Digitized map data resemble fractals much more than they resemble continuous functions which mathematicians normally study. Although certain cartographic objects, including both boundaries and terrain, can be approximated using real functions, the difficulty remains of representing nonperiodic map features as well as ones that are not single-valued, for example, places where curves reverse direction.

Given these similarities, perhaps it is possible to subject strings of coordinates describing lines on maps to algorithms that modify them according to fractal criteria. So Dutton has developed several algorithms based on following consideration:

I. Cannot details be inserted into a chain of coordinates to resemble the features already there?

II. Cannot digitized features be made more prominent, as well as smoothed away?

The term "chain" will be used to denote such strings of coordinates describing cartographic lines. The only restrictions are a chain must contain at least two line segments, i.e., be composed of at least three coordinate pairs, and should intersect one another or themselves only at their end-points.

Here, Dutton gives a procedure which is the latest of these algorithms, and an experimental one for transforming digitized curves fractally, or fractalizing them in self-similar fashion.

Unlike splining and other methods for coordinate reduction and chain smoothing, fractalizing permits features to be exaggerated and smaller-scale features to be introduced into digitized curves, as well as allowing features to be eliminated.

The exaggerations and additions are not arbitrary forms introduced to the chain but are recursions of forms already found there. Because the procedure can be applied recursively, there are geometric similarities between smaller features introduced and large features already existing in cartographic lines.

The procedure described here is the recent approach to fractalization, which reconfigures chains to desired dimensionality and detail. It is given a list of coordinates for an input chain and returns a fractalized version of it in a separate array, transformed according to four parameters:

1) The Sinuosity Dimension (SD)
   The Sinuosity Dimension parameter (SD) prescribes the amount of waviness that chains should possess after fractalization. SD is a real number between 1 (minimum sinuosity) and 2 (maximum sinuosity), and specifies a fractal dimension to

characterize processed chains.

2) The Uniformity Coefficient (UC)
The Uniformity Coefficient parameter (UC) specifies the degree to which junctions may vary from whatever angle SD specifies. When UC is 1 (maximum), the dimensionality of a fractalized chain is held constant at SD throughout its length. When UC is zero, the appearance of chains will be unaffected by fractalizing them.

3) Straightness Tolerances (ST)
Due to the fact that the geometric character of a chain may vary considerably along its extent, it is important to be able to preserve "straight" features while modifying "curved" ones. Without such control, enhancement might introduce major shape alterations where only minor ones were desired. The Straightness Tolerances parameter (ST) specifies the maximum length of a segment allowed to be modified.

4) Smoothing Tolerances (SM)
In a similar but inverse fashion, the Smoothing Tolerance parameter (SM) specifies the smallest segment allowed to be modified. Together, ST and SM define the upper and lower limits for the size of features subject to enhancement and thus constrain the overall amount of added detail.

There is no one "correct" or "best" method of fractal enhancement. The approach presented here is one of many algorithms. Although its mechanics are inherently rigid, its parameters provide a good measure of control over its results. In any case, its sensitivity to local conditions could be considerably improved upon.

That is, rather than imposing an inappropriate fractal dimension at each point along each chain in file, local dimensionality should be allowed to retain its variability.

(3) Michael F. Goodchild's Method

The problems of estimating line length, area, and point characteristics are of increasing concern given the current interest in digital capture, processing, and the storage of geographically referenced data. All three problems are shown to be related to Mandelbrot's theory of fractional dimension D which allows the dependence of each on sampling density to be predicted. The approach of Goodchild of estimating geographic features is based on the conceptual framework of Mandelbrot.

The method of estimating line length, area, and point characteristics of Goodchild is based on the method of Hakanson (1978), which can be described as follows:

1) The length of a line can be defined by overlaying a grid and counting intersections. But the method is not strictly suitable for an analysis of fractal dimension D. Because of counting the intersections between a grid and the shoreline of interest, we expect two intersections for each intersected grid cell, in principle any even number of intersections is possible.

Thus, the scale of the map, which determines the size of the grid, is not strictly related to a sampling interval. It would be more appropriate, in terms of an analysis of fractional dimensionality, to count the number of cells intersected, rather than the number intersections. In other words, counting cells intersected gives estimates that are more simply related to scale, and less to how the map was constructed.

2) A common method of estimating the area of a closed figure on a map is to overlay a grid, and count the number of cells occupied by the figure. "Occupied by" can be interpreted in two ways -- a cell can be counted if its centroid falls within the figure (the centroid rule) or if more than 50% of its area lies in the figure (the majority rule). Clearly the estimate will be greatly improved if the area of each cell intersecting the figure is measured, but this is far more time consuming.

A boundary cell which is intersected and counted by either rule will contributes to an overestimation or underestimation of the area. The error variance in the estimate of area depends on the summation of individual errors from each of the boundary cells. In the case of a very contorted line, the contribution of each cell may be assumed to be independent, so that the total error variance will be simply the sum of the individual values.

3) For the point estimation, the problem is that of determining whether a point lies inside or outside a boundary from a grid cell representation of the boundary and the probability that the characteristics at a randomly chosen point, as determined from a grid representation, are the correct characteristics. This is the probability that the cell centroid or the majority of the cell lies within the same map zone as the point.

Both area and point problems depend on an estimate of n, the number of cells intersected by the figure boundary line. This parameter is directly related to the Hakanson length estimation method, and is identical if the number of cells intersected is used instead of the number of intersections. In this case, The cell side b can be considered the same as the sampling interval,

so n and b can be related through a fractal D:

$$D = \mathrm{Log}(n/n0) \;/\; \mathrm{Log}(b0/b).$$

The formula is from the work of Mandelbrot in 1977, where n, and n0 are the number of intervals and b and b0 are the sampling length of two different intervals.

The concepts and ideas are verified by simulation. A boundary of prescribed dimensionality D can be generated by taking an arbitrary contour of a surface of dimensionality D + 1. In turn, the fractal dimensionality of an arbitrary contour of a surface can be calculated by Fractional Brownian function.

Each of the surfaces used in simulation was generated using a 100*100 sample grid. Since each one has self-similarity property, or constant D, tests were conducted to demonstrate the relationship between cell size and estimation.

The paper has demonstrated that some parameters in area and point estimation are determined by the number of cells intersected by the boundary, n, which is also the important parameter in length estimation and line fractal analysis. Thus all three problems can be placed within the same framework. The performance of n over changes in cell size can be related to a fractional dimensionality parameter of the figure, or if it is a contour, of the surface by extension. The relationships were demonstrated by simulation on self-similar surfaces.

Except for certain range of areas and scales, the D value may not be constant in reality. But it will still provide a very useful summary for fractional dimensionality analysis and length, area, and point estimation.

(4) Method of David Mark & Peter Aronson

In cartographic feature analysis and generalization, Mandelbrot's "fractional Brownian surfaces" have gained considerable attention and have been widely discussed as an appropriate model for the statistical behavior of topographic surfaces. The reason for this situation is that topographic surfaces have the properties of all the fractal models, statistically self-similar and fractional dimensionality. Mark & Aronson (1984) gave an empirical investigation, with applications in geomorphology and computer mapping, on the scale-dependent fractal dimensions of topographic surfaces.

In their paper, they present empirical estimates of the fractal dimensions of topographic samples; then give an evaluation of the fractals model in the context of geomorphology and also the implications of the fractals model regarding

sampling densities for digital elevation models.

In principle, if a computer simulation model produces surfaces that are indistinguishable from real terrain, a considerable step toward a quantitative theory of landforms will have been achieved. Two classes of models should be distinguished: one class is based upon established geomorphic processes, and iteratively "erodes" a surface; the other class is purely statistical, with no physical basis.

Simulations based on geographic processes hold the greatest potential, but have been applied only to highly simplified situations; In contrast, the surfaces simulated using the fractals approach have been very successful, at least in terms of visual appearance, despite the fact that the model lacks any physical basis.

Geomorphologists and cartographers are interested in a class of single-valued fractal surfaces termed fractional Brownian surfaces. These can have fractal dimensions ranging from just greater than 2 (the dimension of a plane) to 3 (the dimension of independent random heights, spatial "white noise").

One characteristic of such a surface, having dimension D, is that the line formed by any plane cut of the surface, such as a contour (horizontal plane) or a profile (vertical plane), will have a fractal dimension D - 1. Another characteristic of fractional Brownian surfaces is that they are scale-free, or called self-similar.

There are many empirical methods to estimate the fractal dimension of a geographic curve or surface. One general approach is the method we mentioned above, the "dividers" relationship between the number of sampling intervals and the interval size. Mandelbrot, Goodchild, Dutton, and Muller all used this method to estimate the dimensions of coastlines. For surfaces, the same method can be used on the contours derived from the surface, and the surface dimension would then be the dimension of the contour plus one.

There is another approach to estimate the fractal dimension of a geographic feature, which is the method just outlined: to count the number of intersected grid cells on the surface boundary.

In their paper, Mark & Aronson estimate the fractal dimension from another important statistical property of fractional Brownian surfaces: the variogram. For a fractional Brownian surface of dimension $2 < D < 3$, the elevation value can be given by the relation:

E[(Zp - Zq)**2] = k(d)**2H

where Zp and Zq are the values of the Brownian function at points p and q, d is the horizontal distance between the points, and the H can be related to fractal dimension by the relation H = 3 - D.

Seventeen Digital Elevation Models were used for this empirical experiment. Three of them are from Appalachian Plateau, four from the Ridge and Valley province, Pennsylvania; nine from the Basin and Range province, Oregon; and one from the Rocky Mountains, Colorado.

From the results of empirical examination of the 17 topographic samples, only 1 had a variogram totally consistent with the concept of self-similarity, and with the model of a fractional Brownian surface.

All of the remaining 16 areas showed some evidence of characteristic scales at which fractal dimension changed, and the dimension was essentially constant over restricted scale ranges. So the characteristics of a fractal model (geographic surfaces are self-similar) are correct only in a certain sense.

There is another very important result from the experiment. For surfaces with high fractal dimension, which are extremely irregular, the autocovariance is low, and points cannot be accurately predicted from the heights of neighboring points. Thus information will be lost as the sampling interval is increased. When the fractal dimension is low, the surface is smooth, and elevations can be interpolated from their neighbors. It is much easier to predict the characteristic of the surface from the neighboring features as the sampling interval is increased.

Perhaps the most common natural phenomenon to be represented in current applications of computer graphics is terrain. Terrain is generally characterized by randomly distributed features that are recognizable by their overall properties, as opposed to specific macroscopic features. The theory of fractals applied to geographic terrain feature analysis will help us to get some general information for feature generalization without considering the accuracy of their physical nature.

## 7.2. Suggested Approach

### (1) General Concepts

The Digital Feature Analysis Data is the data base which is designed to contain cartographic features information in digital form with known geographic control. Each cartographic feature is identified with a descriptor code defining the feature's characteristics. The Digital Feature Analysis Data, when used together with Digital Terrain Elevation Data, constitute Digital Landmass System (DLMS) data. The DLMS data base may be used for the purpose of Sensor Simulation Display, Sensor Prediction Display and other geographic feature generalization.

The purpose of our system is to use the Digital Feature Analysis Data (DFAD) as the input data, which will contain information derived from planimetric, photographic, and intelligence sources. This data is also utilized to collect cultural features which, along with appropriate descriptive information, are converted to digital form for inclusion in the final culture file. Then we process these data(for example, feature classification, feature segmentation, and other feature analysis methods), and generate geographic features in realistic, consistent, natural ways.

Feature analysis of digital data is designed to determine what the physical characteristics of a feature are and which features will be selected for portrayal (areal, linear, point) on the feature manuscript. The selection of features to be portrayed is based on those factors which include feature size, predominant height, and surface material make up. This information is determined by analyzing aerial and ground photography, map source, textual material, and intelligence reports.

Digital Feature Analysis Data is collected at two different levels which are defined and identified as follows:

A) Level 1 DFAD is a generalized description and portrayal of planimetric features. The level 1 data base is intended to cover large expanses of the earth's surface and has relatively large minimum size requirements for portrayal of planimetric features.

B) Level 2 DFAD is highly detailed description and portrayal of planimetric features. The level 2 data base is intended to cover small areas of interest and has smaller minimum size requirements for portrayal of planimetric features.

A recurrent problem in generating realistic pictures by computers is to represent natural irregular objects and phenomena

with a scientific and mathematic method. We think that the best way to do this is to use the fractal theory described by Mandelbrot.

That is, to calculate the fractal dimension of a feature according to the input data, modify and control the degree of irregularity of the feature by some parameters which their value can be determined from the information in DFAD, and put the results in the object data base.

The following sections are general descriptions for the fractal dimension analysis on the Digital Feature Analysis Data, which include the input data description, methodology description, and output data structure description.

(2) Input Data of the System

Digital Feature Analysis Data file consists of digitally encoded descriptive data about cartographic features within a geographic area which are uniquely identified on coded feature analysis manuscripts. Each manuscript on the file consists of a descriptive header record, a Data Set Identification record, an Accuracy record and one or more feature records.

The header record also defines the latitude and longitude of an origin, which is South and West of all digitized coordinates on the manuscript. All other coordinates are stated relative to this origin. The feature records contain digitally encoded descriptive information and digitally encoded culture features (point, areal, and linear features) from the Feature Analysis manuscript.

A) Manuscript Header record

This record provides minimal identification information for DFAD, which are the coordinate lists for the geographic feature on the manuscript.

The fields of record is defined as:

* Latitude of Manuscript Origin --- For level 1 manuscripts, the latitude value of the origin is a whole minute and exactly one minute south of the manuscript's southwest corner. This configuration is necessary to ensure orderly manuscript sorting when multiple manuscripts are placed on one data file. The offset origin for level 2 manuscripts may be any value expressed to tenth of a second that is approximately one minute south of the manuscript's southwest corner.

* Longitude of Manuscript Origin --- For level 1

manuscripts, the longitude value of the origin is a whole minute and exactly one minute west of the manuscript's southwest corner. This configuration is necessary to ensure orderly manuscript sorting when multiple manuscripts are placed on one data file. The offset origin for level 2 manuscripts may be any value expressed to tenths of a second that is approximately one minute west of the manuscript's southwest corner.

* Estimated Maximum Change in Latitude of Digitized Coordinates is the maximum value to the highest bounding minute even though the field would allow values to be expressed to tenths of a second. Because the value is greater than or equal to the maximum latitude value of any feature, it may be outside the manuscript.

* Estimated Maximum Change in Longitude of Digitized Coordinates is the maximum value to the highest bounding minute even though the field would allow values to be expressed to tenths of a second. The value may be outside the manuscript because of the same reason mentioned above.

(B) Feature Record

In the DFAD data base, each manuscript area may consist of a series of three types of features (point, linear, and areal) which describe and locate natural and manmade objects which appear on the earth's surface.

The areal and linear features are depicted by a series of delta pairs, referenced to the manuscript origin, and is defined by specific attributes. A point feature is depicted as a delta pair, referenced to the manuscript origin, which identifies the center of the feature and is defined by specific attributes. The delta pair is a coordinate in a feature, which is represented by different measurements in integer tenths of second which, when added to the value of the manuscript origin, describe the coordinates location.

All natural and manmade objects which occur on the earth's surface are currently divided into 14 homogeneous groupings based on the object's predominant exposed surface material, in accordance with the categories listed below:

Surface Material Category 1 (Metal)
Surface Material Category 2 (Part Metal)
Surface Material Category 3 (Stone/Brick)
Surface Material Category 4 (Composition)
Surface Material Category 5 (Earthen Works)
Surface Material Category 6 (Water)
Surface Material Category 7 (Desert/Sand)

Surface Material Category 8 (Rock)
Surface Material Category 9 (Concrete)
Surface Material Category 10 (Soil)
Surface Material Category 11 (Marsh)
Surface Material Category 12 (Trees)
Surface Material Category 13 (Snow/Ice)
Surface Material Category 14 (Asphalt)

The surface material criteria applies to all areal, linear, and point features in accordance with the specification requirements, and is very important for the feature generalization.

(3) Methodology Description

(A) Estimation of the Feature Fractal Dimension

The approach we will use to estimate the fractal dimension of the features on the manuscript of DFAD data file is based on the framework of fractal dimension analysis by Mandelbrot. That is, the estimation will be based on the relation:

$$D = Log(x/x0) \;/\; Log(b0/b).$$

I. Linear Feature

Linear features are the rivers, roads, coastlines, and the other geographic lines. In order to calculate the fractal dimension of a geographic line, we should find the number of segments used to measure the length of a given line and the length of each segment.

For a geographic line on the manuscript, we can know the number of delta pairs (or the coordinates) of the line from the input data. From the first and last delta pairs, the straight line distance between two coordinates can be calculated, and the distances between every consecutive delta pairs can be calculated too. Theoretically, the number of segments of the line can be found and fractal dimension of the line can be measured easily using the formula just mentioned above.

But real geographic lines are not made up of a set of consecutive equal line segments, some kind of assumption must be used in empirical approach for the fractal dimension measurement. Figure 7.1 describes an algorithm that may be used to find an appropriate segment length.

This procedure can be executed recursively and several different segment length may be found if the distances between each consecutive delta pairs of the geographic line to be measured are very different. Then each part of the fractal

dimension of the line can be calculated locally using the results of the procedure SEGMENT. If the distances between each

```
procedure SEGMENT(A: delta pairs of the line);
begin
  Find a series of consecutive and approximately equal delta
    pairs with values within a given range from array A;
  Find the length of this part of the line;
  Rearrange the rest of the delta pairs
    and put into a separate array B;
  SEGMENT(B: rest of the delta pairs of the line);
end;
```

Figure 7.1 Algoirthm for Finding Segment Length

consecutive delta pairs is within the given range of threshold (in other words, they remain same approximately), then the simple relation D = Log(N) / Log(1/r) will apply to this situation.

II. Areal Feature

For the areal features, the same analysis method can be applied to the contours derived from the feature's horizontal plane, and the fractal dimension of the areal surface will be the fractal dimension of the contour plus one.

One important factor must be considered in the fractal analysis of areal feature. That is, all areal features, with the possible exception of feature one, are geographically closed, i.e., the last delta pair value of an areal feature is geographically identical to the first delta pair. This geographic closure may occur at any location along the areal feature's boundary. So the special technique may be used to do fractal dimension analysis when the procedure SEGMENT is implemented.

(B) Generalization of Fractal Features

Traditional techniques used in computer graphics have been based on the assumption that objects are essentially a collection of smooth surfaces which can be mathematically described by deterministic functions. Natural objects, however, such as stones, clouds, trees, terrain, etc. are characterized in general by no such regular features or simple macroscopic structures, and these methods have been less effective in modeling them.

To capture the macroscopic features to be modeled involves significant time and/or space requirements because the features are often represented explicitly using large amounts of data. In many applications, however, one is interested in achieving

sufficient realism in the representation of the objects for their nature to be easily recognizable. For example, one may wish to generate a mountain range which is obviously a mountain range but which is not intended to represent any particular real-world mountains.

In such a case, one is interested only in the general size, shape, and position of the mountain range to be modeled. Where one wishes to display real-world data, the addition of suitable information at various scales may be used to enhance the precision of the representation.

The method we will describe here is based on the framework of A. Fournier & D. Fussell (1982), which is a stochastic model of an object, which is defined to be a model where the object is represented by a sample path of some stochastic process of one or more variables.

For the computer graphics system, the modeling is the part where the objects are defined in terms of the basic building blocks:the modeling primitives, such as points, lines, polygons, and parametric patches. Besides, the stochastic modeling system consists of: (1) an appropriate object to be modeled; (2) a stochastic process to model it with; (3) an algorithm to compute the sample paths of this process.

Mandelbrot and van Ness introduced the term "fractional Brownian motion" (fBm) to denote a family of one-dimensional Gaussian stochastic processes which provide useful models for many natural time series. After that, many extensions of fBm have been studied, including, in particular, terrains in two dimensions (a detailed discussion of fBm is out of the scope of this paper).

An algorithm was constructed by Fournier & Fussell to compute the sample paths for fractional Brownian motion in computer graphics. Besides the efficiency factor to be considered to make a sample path generating algorithm, two other properties are important for any modeling primitives in computer graphics.

The first one is called "internal consistency," which is the reproducibility of the primitive at any position in an appropriate coordinate space and at any level of detail. That is, a modeling primitive should be rendered in such a way that its features do not depend on its position or orientation in space.

The other property of modeling primitives is called "external consistency," which refers to the continuity properties of adjacent modeling primitives. If modeling primitives are intended to share a common boundary, it must be possible to

ensure that they are indeed continuous across this boundary at any scale at which they may be rendered.

See Figure 7.2 for an algorithm which uses these properties.

```
procedure fractal(maxlevel, seed: integer; h, scale: real);
var first, last: integer; ratio, std: real;

  procedure subdivide(f1, f2: integer; std: real);
  begin
    fmid := (f1 + f2) div 2;
    if (fmid <> f1) & (fmid <> f2) then begin
    { Gauss function processing }
    stdmid := std * ratio;
    subdivide(f1, fmid, stdmid);
    subdivide(fmid, f2, stdmid);
  end;  {* subdivide *}

begin
  first := 0;
  last := 2**maxlevel;
  { Gauss function processing }
  ratio := 2**(-h);
  std := scale * ratio;
  subdivide(first, last, std);
end.  {* fractal *}
```

Figure 7.2   An algorithm for Fractal Brownian Motion

The algorithm recursively subdivides the interval [first, last] and generates a scaler value at the midpoint proportional to the current standard deviation times the scale. Variable h is a parameter which can be determined by the "fractal dimension" computed from last section. Maxlevel determines the level of recursion needed.

(C) Shape Control of Geographic Feature

In our methodology, the different kind of geographic features will be generated by fractal generators, which their fractal dimension are identical to the fractal dimension of the features to be generated.

Actually, the different geographic features in nature will have different geographic shapes, but it is possible that they have the same fractal dimension. It is not practical to generate different kinds of geographic lines and contours by limited fractal generators depending upon the fractal dimension.

In order to solve this problem, another parametrically controlled mechanism is introduced to give the feature generator mechanism more flexibility, i.e., different curves or surface boundaries can be generated under the control of parameters. Their value will decided according to their Surface Material Category, even though the features have the same fractal dimension. A separate procedure is needed to set the parameter values.

I. Waviness Parameter (WP)

The Waviness Parameter (WP) is defined as the amount of waviness that curves should possess after fractalization, representing\the degree of waviness control during processing. WP can be a real number between 0 ( minimum waviness ) and 1 ( maximum waviness). When WP is zero, the appearance of geographic curves will be unaffected by fractalizing them. When WP is 1, the maximum waviness factor will be considered during fractalizing process.

II. Straightness Parameter

The Straightness Parameter (SP) is defined as the length of a segment allowed to be modified during the fractalizing. SP is also a real number between 0 (minimum straightness) and N ( maximum straightness ). The number N is less than or equal to the smallest length of segments of a geographic line to be fractalized. Without the SP parameter, the process of fractalization might introduce some shape alterations which are not desired. SP defines the upper and lower bounds for the length of features subject to fractalizing and constrains the overall amount of generalization detail.

We can not expect that the geographic features generated by the fractal dimension analysis methods described above are accurate descriptions of real objects of in nature. Actually, our main concern is to generate different kinds of realistic objects according to their characteristics, such as their irregularity, which described by the fractal dimensionality, instead of the original geographic shape of these objects.

7.3. System Output (to be completed in the future)

Separated arrays are needed to contain the data structures of each geographic feature. The arrays may store the detailed coordinates list of the generated features and the header information to distinguish different features in the object data base.

References

BURROUGH, P.A., 1983, Multiscale sources of spatial variation in soil: I. The application of fractal concepts to nested levels of soil variation: Jour. of Soil Sci., 34, 577-598.

DUTTON, G.H., 1981, Fractal enhancement of cartographic line detail: The American Cartographer, 8, 23-40.

FOURNIER, A., FUSSELL, D. and CARPENTER, L., 1982, Computer rendering of stochastic models: Graphics and Image Processing, Comm. of ACM, 25, 371-384.

GOODCHILD, M.F., 1980, Fractals and the accuracy of geographic measures: Mathematical Geology, 12, 2, 85-98.

MANDELBROT, B., 1975, Stochastic models for the earth's relief, the shape and the fractal dimension of the coastlines, and the number-area rule for islands: Proceedings of National Acdamic Science of USA, 72, 3825-3828.

MANDELBROT, B., 1977, Fractals, Form, Chance, and Dimension, San Francisco, Freeman, 365p.

MANDELBROT, B., 1982, The Fractal Geometry of Nature, San Francisco, Freeman, 468p.

MARK, D.M. and ARONSON, P.B., 1984, Scale-dependent fractal dimensions of topographic surfaces: An empirical investigation, with applications in geomorphology and computer mapping: Mathematical Geology, 16, 671-683.

MULLER, J.C., 1986, Fractal Dimension and Inconsistencies in cartographic line representations: The Cartographic Journal, 23, 123-130.

ROY, A.G., GRAVEL, G. and GAUTHIER, C., 1987, Measuring the dimension of surfaces: A review and appraisal of different methods: Proceedings, AUTO-CARTO 8, 68-77.

WEIBEL, R., 1987, An adaptive methodology for automated relief generalization: Proceedings, AUTO-CARTO 8, 42-49.

## 8.0. Appendix I

### PRODUCT SPECIFICATIONS FOR

### DIGITAL FEATURE ANALYSIS DATA (DFAD)

Digital Feature Analysis Data (DFAD) product specifications, Second Edition, was published by Defense Mapping Agency on April 23, 1986. These specifications are designed to provide information for the preparation and use of Digital Feature Analysis Data (DFAD) to support various weapons and training systems. DFAD is designed to contain cartographic features in digital form with known geographic control. Each cartographic feature is identified with a descriptor code defining the feature's characteristics.

### 1. Introduction

These specifications deal primarily with the derivation of cultural data from various planimetric, photographic, and intelligence sources. This data is utilized to collect cultural features which, along with appropriate descriptive information, are converted to digital form for inclusion in the final culture file.

Digital Feature Analysis Data is collected at two different levels which are defined and identified as follows:

A. Level 1 DFAD is a generalized description and portrayal of planimetric features. The level 1 data base is intended to cover large expanses of the earth's surface and has relatively large minimum size requirements for portrayal of planimetric features. The density of detail approximates that of medium scale (i.e., 1:200,200 - 1:250,000) cartographic products. The minimum dimensions of a DFAD level 1 manuscript are 5 minutes by 5 minutes, and the maximum dimensions of a DFAD level 1 manuscript are 1 degree by 1 degree.

B. Level 2 DFAD is a highly detailed description and portrayal of planimetric features. The level 2 data base is intended to cover small areas of interest and has smaller minimum size requirements for portrayal of planimetric features. The density of detail approximates that of 1:50, 00 scale cartographic products. The minimum dimensions of a DFAD level 2 manuscript are 2 minutes by 2 minutes, and the

maximum dimensions of a DFAD manuscript are 1 degree by 1 degree.

The horizontal datum for DFAD is the World Geodetic System (WGS).

2. Feature Characteristics

In the DFAD data base, each manuscript area may consist of a series of three type of features (point, linear, and areal) which describe and locate natural and manmade objects which appear on the earth's surface.

A. An areal feature is depicted by a series of delta pairs, referenced to the manuscript origin, and is defined by specific attributes. These delta pairs completely enclose an object or group of related objects. The areal feature is defined as being homogeneous. All areal features contain an implicit delta pair numbering system which starts with delta pair one and progresses continually and sequentially until the feature area has been completely delimited in a counter-clockwise direction.

   All areal features (with the possible exception of feature one), are geographically closed, i.e., the last delta pair value is geographically identical to the first delta pair. The minimum number of delta pairs which define an areal feature is four, the maximum is 8191.

B. A linear feature is also depicted by a series of delta pairs. A linear feature's length is normally more significant than its width. The length of a linear feature is defined as the sum of the distances between the individual delta pairs of the feature. The width is specified as a width normal to the center line of a feature.

   All linear features contain an implicit delta pair numbering system which starts with delta pair one and progresses continually and sequentially until a line segment or a series of line segments have been defined. Linear feature are not closed to form a continuous outline. The minimum number of delta pairs which define a linear feature is two, and the maximum is 8191.

C. A point feature is depicted as a delta pair, which identifies the center of the feature and is defined by specific attributes. A point feature may represent an object with a single delta pair or a group of like objects with multiple delta pairs. All point features contain an implicit delta pair numbering system which starts with delta pair one and may, in special cases such as powerline pylon strings, progress continually and sequentially until a group

of like objects has been defined. The minimum number of delta pairs which define a point feature is one, and the maximum number for group objects is 2047 (however, the number is currently limited to 99).

Each feature is identified by a unique number code identifier referred to as a Feature Analysis Code (FAC), which is contained in a manuscript area in ascending order.

A hierarchy system is used to classify the features in a manuscript area according to feature type and significance. Within a manuscript area, features with lower FAC numbers are masked by higher numbered features occupying the same position.

3. Feature Descriptor

Feature descriptors are the various attributes, located in the feature header record, which serve to identify and define specific features in the DFAD data base.

(1) Feature Analysis Code (FAC) Number
Each feature header in a manuscript area contains a unique numerical identifier (FAC). These FAC numbers range from 1 to a maximum of 16, 383.

(2) Feature Type
Each feature in the DFAD data base is specified as either a point, linear or areal feature. The feature type field is:
Point feature 0
Linear feature 1
Areal feature 2

(3) Height
The height field defines an object's elevation above or below the terrain/water surface. The height is coded in the final file as 1/2 the measured value, which range from -511 to +511.

(4) Feature Identification (FID) Code Number
The feature identification field is currently a three digit code which specifies the nature of a feature. The allowable FID code range from 1 to 1023.

(5) Surface Material Category (SMC)
All natural and manmade objects which occur on the earth's surface are currently divided into 14 homogeneous groupings based on the object's predominant exposed surface material in accordance with the categories listed below:

Surface Material Category 1 (Metal)
Surface Material Category 2 (Part Metal)
Surface Material Category 3 (Stone/Brick)

Surface Material Category 4 (Composition)
Surface Material Category 5 (Earthen Works)
Surface Material Category 6 (Water)
Surface Material Category 7 (Desert/Sand)
Surface Material Category 8 (Rock)
Surface Material Category 9 (Concrete)
Surface Material Category 10 (Soil)
Surface Material Category 11 (Marsh)
Surface Material Category 12 (Trees)
Surface Material Category 13 (Snow/Ice)
Surface Material Category 14 (Asphalt)

(5) Number of Structures
The number of structures field applies only to areal features with structures SMC 1, 2, 3, or 4 and specifies a code for the density of structures within that areal feature. The number of structures code ranges from 0 to 13.

(6) Percent of Tree Coverage
The percent of tree coverage field applies only to areal features with structures SMC 1, 2, 3, or 4 and specifies a code for the percent of tree coverage with the area represented by the feature. The percent of tree coverage represents the tree foliage, not the number of trees. This percentage is currently standardized as 0%, 10%, or 30% and coded in the final file as 1/10 the standardized percentage.

(7) Percent of Roof Coverage
The percent of roof coverage field applies only to areal features with structures SMC 1, 2, 3, or 4 and specifies a code for the percent of roof coverage with the area represented by the feature. This percentage is currently standardized as 20%, 30%, 80%, or 100% and coded in the final file as 1/10 the standardized percentage.

(8) Directivity
Directivity applies only to linear features, and specifies one of three types of directivity (UNI, BI, OMNI) which describes the side(s) of a feature which have the greatest reflectivity potential:

UNI --- visually significant or reflective from one side only; 1
BI --- visually significant or reflective from two sides only; 2
OMNI -- visually significant or reflective from all sides; 3

(9) Orientation
Orientation applies only to point features, and specifies a code for the angular displacement between true north and the major axis of a feature.

(10) Length and Width
Length and width are both coded for point features, width

only is coded for linear features, and neither length nor width is coded for areal features. The length and width fields specifies a feature's dimensions as 1/2 the measured value. The length and width codes range from 0 to 127.

4. Surface Height Differential

Each homogeneous surface material area shall be analyzed to determine the predominant height (not average) and shall be subdivided into homogeneous surface groupings. Predominant height is defined as the height of 51% or more of the structures within the area.

The predominant height of a homogeneous surface material area may be increased to indicate the presence of significantly taller structures within the area. If 15% or more of the area is occupied by structures which are a minimum of 6 meters taller than the predominant height, the height differential of the area shall be multiplied by the percentage of the area which is occupied by the taller structures. The result shall be added to the predominant height to produce an adjusted predominant height.

5. Sample Listing of Unique Significant Features

Unique significant features are defined as features that are significant but which do not meet the minimum dimensions of a homogeneous surface material grouping. The unique features that meet the minimum specifications will be delineated as areal, point or linear features on the feature manuscript. The selection of features is based upon those factors which include such considerations as type of feature, surface material makeup, predominant height, and minimum dimension requirements.

A. Areal Features

(1) Parking Area and Squares
These features are hard surfaced areas of concrete, stone, brick or asphalt at ground level. The surface material shall be SMC 9 or 14 and requires no height value.

(2) Metal Ore Slag Dumps
Slag Dumps are of importance because of the high metal content. The SMC shall be standardized as "2", and the predominant height will be considered to be the maximum height of the slag piles above the surrounding terrain.

(3) Islands
Islands are of particular importance because of the land water contrast. Islands will be treated as all other land bounded by a coastline and described as SMC 10. Islands or exposed rocks that are too small to portray as areal features will be portrayed as linear or point features.

Features of this type require a height value and will be described as SMC 3. Height will be the highest point of the island.

(4) Storage Areas
Permanent storage areas such as ship, airplane and automobile storage areas, or scrap yards will be portrayed if the minimum size requirements are met and the surface material category shall be standardized as "1". Mineral storage areas (coal, etc. ) will be assigned the SMC that most closely applies.

(5) Quarries
Quarries that cannot be portrayed as an areal feature will be portrayed as a linear feature. The surface material will be standardized as "3". Height shall be measured from the surface terrain elevation to the deepest part of the quarry.

## B. Linear Features

(1) Rivers
All rivers which constitute the principal drainage network of the region will be portrayed. Rivers will have directivity coded as bidirectional and the SMC standardized as "6". Rivers will be portrayed as continuous features throughout their course.

(2) Railroads
All railroad will be portrayed as continuous linear features throughout their route. The height of railroad is standardized as zero, the directivity is coded as bidirectional, and the SMC is standardized as "2".

(3) Roads
Roads can be treated as railroads except that the directivity is coded as omni-directional, and the SMC shall be "9" or "14".

(4) Bridges
All SMC 1-4 bridges equal to or greater in length than 150 meters level 1(or 30 meters level 2) will be portrayed as linear features, and all SMC 1-4 bridges 10 meters or more in length but less than 150 meters level 1 (or 30 meters level 2) will be portrayed as point features.

(5) Embankments
An embankment is defined as a predominantly earthen structure used to support a road/railroad or to impound water. All embankments are standardized as SMC "5", and height is the height of the highest portion of the embankment above the surrounding terrain.

(6) Walls
Only walls constructed of steel, stone or concrete (SMC 1-3) will be selected for portrayal. Height shall be considered as the height above the surrounding terrain.

(7) Airfield Runways
The feature is a hard surface area such as concrete or asphalt. All of this kind of features shall be SMC "9" or "14", and requires no height value.

C. Point Features

(1) Powerline Pylons
Powerline pylons may be portrayed by either of two methods:

Method 1: Each pylon is plotted individually and a separate FAC number applies to each pylon portrayed.

Method 2: Strings of pylons are portrayed by positioning the first and last pylons of the string and connecting them with a straight line. Only straight segments of evenly spaced pylons may be portrayed by this method. A separate FAC number will be assigned to each segment. The SMC are dependent upon the predominant material of construction.

(2) Tanks and Buildings
Only SMC 1, 2, or 3 structures will be selected for portrayal. If structures are too densely spaced to portray as individual features, a representative pattern will be selected for portrayal. These features may also be shown as linear features when the length of the feature is equal to or greater than 150 meters level 1 or 30 meters level 2.

6. DFAD File Description

The off-line Digital Data Base is a method of recording culture (Feature analysis) data on magnetic tape. The format is intended for the purpose of production, storage, and exchange of culture data. The culture file consists of digitally encoded descriptive data about cartographic features within a geographic area which are uniquely identified on coded feature analysis manuscripts.

Each manuscript on the file consists of a descriptive header record, a Data Set identification record, an accuracy record and one or more feature records.

A. The header record contains index and reference information pertaining to a feature analysis manuscript. The header record also defines the latitude and longitude of an origin, which is South and West of all digitized coordinates on the

manuscript. All other coordinates are stated relative to this origin.

B. This record provides identification and security information relating to the DFAD. The record is fixed length consisting of 648 ASCII characters. Each character is represented by 1 tape frame or 8 bits. Certain fields in the DSI record are duplicated in the manuscript header record. These fields are required to match.

C. The accuracy record provides accuracy information relating to the DFAD. The record is fixed length consisting of 2700 ASCII characters. Each character is represented by 1 tape frame or 8 bits.

D. The feature records contain digitally encoded descriptive information and digitally encoded culture features from the Feature Analysis manuscript.

Each feature record consists of feature descriptive information which discussed in section 3 according to three different types (point, linear, or areal feature).

## 9.0. Appendix II

### LISTING OF SAMPLE FEATURE DESCRIPTIONS

This appendix gives the part of sample descriptions for feature analysis which represent some very important culture features. The standard primitives will be implemented for these features portrayal.

### I. INDUSTRY FEATURES

1. Quarry
Quarry can be portrayed as either an areal feature or a linear feature. The surface material will be standardized as 3. Height shall be measured from the surface terrain elevation to the deepest part of the quarry. Detailed description can be found in DFAD sample description file which is referred to FID number 102.

2. Plant
Plant can be portrayed as an areal feature, a linear feature, or a point feature. The surface material will be standardized as 1, 2, or 3. The minimum height for the most plants are 5 meters. Detailed description can be found in DFAD sample description file which are referred to FID number from 112 to 136.

3. Building
Building can be portrayed as an areal feature, a linear feature, or a point feature. The surface material will be standardized as 1, 2, or 3. The minimum height is 3 meters. Detailed description can be found in DFAD sample description file which is referred to FID number 181.

### II. TRANSPORTATION FEATURES

1. Railroads
All railroads will be portrayed as continuous linear features throughout their route. The surface material will be standardized as 2. Height is standardized as zero, and the directivity is coded as bidirectional. The FID number is referred to 201.

2. Interchanges
The interchanges will be portrayed as point features. Some

interchanges can also be portrayed as linear features and assigned the corresponding road FID number, if possible. The surface material will be standardized as 9. Height is standardized as zero. The FID number is referred from 230 to 239.

3. Roads
Roads can be treated as railroads (i.e., to be portrayed as linear features) except that the directivity is coded as omni-directional. The surface material will be standardized as 9 or 14. Height is standardized as zero. The FID number is referred to 240.

4. Bridges
Bridges will be portrayed as linear features (equal to or greater in length than 150 meters level 1 or 30 meters level 2) or point features (10 meters or more in length but less than 150 meters level 1 or 30 meters level 2). The surface material will be standardized as 1 through 4. Height is standardized as 10 meters. The FID number is referred to 260.

III. OTHER FEATURES
1. Stadium
Stadium will be portrayed as an areal feature, a linear feature, or a point feature. The surface material will be standardized as 2 or 3. Height is standardized as 10 to 12 meters. The FID number are referred to 321 through 323.

2. Towers
Towers will be portrayed as point features. The surface material will be standardized as 1. Height can be different from 24 meters to 150 meters. The FID number are referred to 501 through 532.

3. Powerline Pylons
Powerline pylons may be portrayed by either of two methods:

Method 1: Each pylon is plotted individually and a separate FAC number applies to each pylon portrayed.

Method 2: Strings of pylons are portrayed by positioning the first and last pylons of the string and connecting them with a straight line.

The surface material will be standardized as 1. Height is standardized from 10 to 24 meters. The FID number are referred to 536 through 544.

4. Airport
Airport will be portrayed as an areal feature, a linear feature, or a point feature. The surface material will be standardized as

3. Height will be standardized as 10 meters. The FID number is referred to 701.

5. Tanks
Tanks will be portrayed as areal features, linear features, or point features. The surface material will be standardized as 1. Height will be standardized as 10 meters. The FID number is referred to 801.

6. Closed Storage
Storage will be portrayed as an areal feature, a linear feature, or a point feature. The surface material will be standardized as 3. Height will be standardized as 10 meters (the minimum height for SMC 1, or 2 will be 3 meters). The FID number is 820.

7. Parking Area
Parking area will be portrayed as an areal feature. The surface material will be standardized as 9 or 14. No height value is required for parking area. The FID number is referred to 863.

8. Desert
Desert will be portrayed as an areal feature. The surface material should be 7. No height value is required. The FID number is referred to 906.

9. Islands
Islands are of particular importance because of the land water contrast. Islands will be treated as areal features and described as surface material 10. Islands or exposed rocks that are too small to portray as areal features will be portrayed as linear features or point features with SMC 3. Linear or point features require a height value which will be the highest point of the island. The FID number are referred to 902 or 915.

10. Salt Water (Sea)
Sea will be portrayed as areal feature or linear feature. The surface material should be 6. Height must be zero unless portrayed with supporting feature. The FID number is referred to 930.

11. Trees
Trees will be portrayed as areal features or linear features. The surface material will be 12. Height for the tree is standardized as 16 meters for trees less than 30 meters tall; and 30 meters for trees taller than 30 meters. The FID number are referred to 952 through 954.

12. Snow/Ice Areas
Snow/Ice areas will be portrayed as areal features. The surface material will be 13. No height value is required. The FID number is referred to 960.